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PROCEEDINGS OF
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VOL. 14.

WIRELESS SECTION: CHAIRMAN'S ADDRESS*

By A. J. GILL, B.Sc.(Eng.), Member.†

(*Address delivered 2nd November*, 1938.)

I propose to review some of the more important developments in radio engineering which have been carried out by the Post Office Engineering Department, or with which that Department has been associated, during the last year or so.

The first item which I have chosen is that of ultra-short-wave telephone equipments.

In the British Isles there are many short routes which are eminently suited for exploitation by ultra-short waves. For example, there are the Straits of Dover, the mainland and Channel Islands, the mainland and Scilly Isles, England to the Isle of Man, England to Ireland, and many possible routes in the Scottish Islands. In some cases submarine cables already exist over these paths, but, owing to the growth of traffic, additional circuits are constantly being required (see Fig. 1).

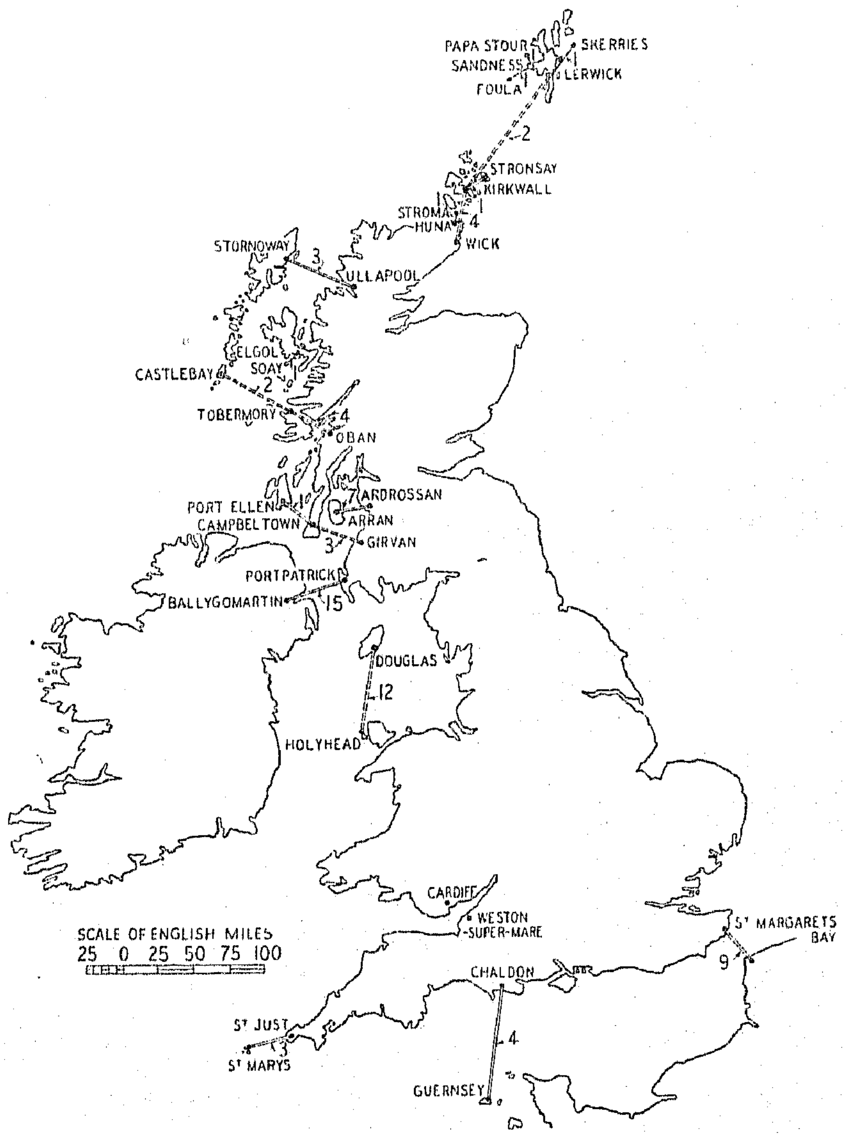

Fig. 1.—Position of G.P.O. ultra-short-wave radio links, 1st February, 1938.

═══ 4-wire trunk circuits (working).
┅┅┅ 4-wire trunk circuits (authorized and/or under construction).
—— radio-phonogram circuits (working).
Figures indicate number of working or authorized circuits.

Equipment for service of this type has been the subject of development for the past 10 years and has now reached an entirely reliable stage.

For short ranges up to about 40 miles a transmitter has been developed giving an unmodulated output of 1 watt at frequencies up to 80 Mc./sec. A crystal-controlled oscillator at a frequency one-quarter of the final frequency controls the transmitter, which is worked from an a.c. supply and can be left unattended. The transmitter can be modulated from 100 to 10 000 c./sec. With this range two telephone circuits are provided in the transmitter by means of carrier channel equipment.

For longer-distance services where only a single circuit is required an amplifier has been designed to follow the above transmitter. This is a linear Class B amplifier which amplifies the modulated signal to give a carrier power of 10 watts unmodulated signal.

These units are designed for standard rack mounting, and with their power packs occupy respectively 14 in. and $17\frac{1}{2}$ in. of panel space. For services over distances of the order of 100 miles there has been produced a transmitter with unmodulated carrier power of 100 watts. This is contained in a cubicle 2 ft. square and 6 ft. high, and is also designed for unattended operation.

The crystal drive unit is similar to the 1-watt transmitter; it is followed by two pentode stages and a stage of balanced triodes of the carbon-anode type.

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* Reprinted from *Journal I.E.E.*, 1939, vol. 84, p. 248.
† Post Office Engineering Department.

The order of frequency control is ± 10 parts in 10^6. Anode modulation is used in this transmitter, and 100 % modulation is possible by either of two modulator units:—

(a) A 30–10 000-c./sec. modulator with negative feedback for two speech channels or one music channel.

(b) A 15–100-kc./sec. modulator for a multi-channel service.

This latter modulator will allow the radio service to be inserted in tandem with standard 12-channel carrier telephone systems working over the range 12–60 kc./sec. Alternatively it will permit the use of multi-channel equipment produced for the co-axial cable system over the frequency range 60–100 kc./sec. A transmitter of still higher power has been developed for operation on a new service to the Shetland Islands. It is similar to the 100-watt transmitter, but an additional balanced triode stage provides a final unmodulated carrier output of 350 watts up to 80 Mc./sec. Modulation of 30–10 000 c./sec. per sec. is applied to the anode of the final stage.

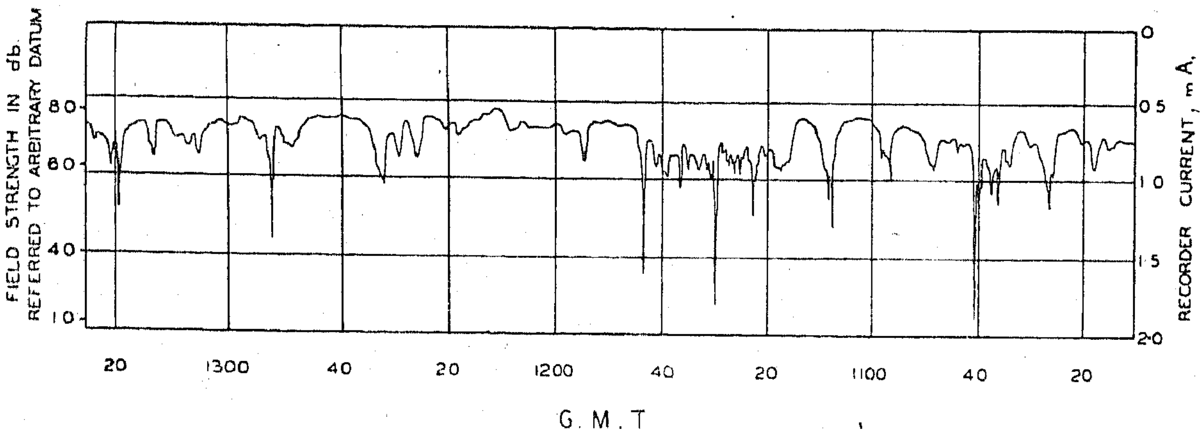

Fig. 2.—Guernsey–Chaldon 5-metre horizontally-polarized transmission. Typical fading record.

The receiver used in conjunction with these transmitters is also designed for unattended operation from a 230-volt 50-cycle a.c. supply.

The receiver is of the superheterodyne type having an intermediate frequency of 3 000 kc./sec. The beating oscillator is crystal-controlled and is similar to the drive unit in the 1 watt transmitter. This feature ensures stability of adjustment over prolonged periods. The audio-frequency response of the normal receiver is uniform from 100 to 10 000 c./sec., but when it is to be used in connection with multi-channel systems working over a wider modulation band the frequency response is suitably widened.

As mentioned previously, these equipments are standardized for a.c. power supplies. Where a d.c. public supply only is available a rotary convertor is used. Where no public power supply is available it is the practice to provide in the higher-powered installations heavy-oil-engine-driven alternators in duplicate. For low-powered installations it is usual to provide a battery, charged intermittently by a heavy-oil-engine-driven generator, together with a rotary convertor.

The equipments described are already in commercial service. In addition, later patterns have been produced for experimental work on higher frequencies up to 150 Mc./sec. (2 m. wavelength). Low-powered transmitters similar to the 1-watt transmitter, but with an output of 0·5 watt with quartz-crystal control, have been constructed and used successfully. For longer-range investigations higher-powered transmitters with a peak output of 100 watts at 144 Mc./sec. are now undergoing test. These sets comprise—

Crystal oscillator on approximately 12 Mc./sec. using a low-frequency pentode-type valve.
1st frequency multiplier (tripler) using a low-frequency pentode-type valve.
2nd frequency multiplier (doubler) using a low-frequency pentode-type valve.
Intermediate buffer amplifier using a low-frequency pentode-type valve.
3rd frequency multiplier (doubler) using 2 R.C.A. 807 ("beam" valves).
Final amplifier using 2 D.E.T. 12 (graphite-anode triodes).

Provision is made for the use of various types of modulators so that investigations can be carried out on telephony, carrier telephony, or television.

A similar development has been necessary in regard to receivers, and the superheterodyne receiver has been modified by the substitution of two acorn pentode valves in push-pull for the first detector. The tuned input circuit is provided by a variable inductor consisting of two parallel copper tubes ½ in. outside diameter and 18 in. long. A short-circuiting bar clamped across these tubes serves as the tuning adjustment. In order to avoid complicating the crystal-driven beating oscillator, the first detector is supplied with a frequency of half the normal value; this proves to be entirely satisfactory. The design of this receiver is such that thermal-agitation noise of the tuned input circuit predominates over other sources of noise, and this condition is a good criterion of performance of any receiver.

The results of propagation studies on these higher frequencies are not yet available, but during the past two years studies have been made on the Channel Islands commercial service working on 37·5 and 60 Mc./sec. between Chaldon (near Lulworth Cove) and Guernsey. The total length of path is 85 miles, and as the elevations of the aerials at Chaldon and Guernsey are 500 ft. and 270 ft. respectively, the path is non-optical. The method of observation gives a continuous graphic record of the received field strength referred to an arbitrary datum (see Fig. 2). The recorder actually plots the anode current of the first stage of the intermediate-frequency amplifier. Owing to the action of the automatic gain control on the receiver, this anode current is a function of the received field strength. For calibration purposes it is assumed that the signal/noise ratio at the output of the receiver is, for constant modulation depth, directly proportional to the received field strength. The actual recorders have accordingly been calibrated in terms of signal/noise ratio for 100 % modulation against recorder currents.

The records obtained over the past two years show that considerable fading exists on both the 37·5- and 60-Mc./sec. transmission, being more severe on the higher frequency. The depth of fades is under exceptional circumstances as much as 60 db., resulting in complete " wipe out " of the received field. Normal fading of 30 to 40 db. is compensated approximately by the automatic gain control of the receiver. The duration of the fades is usually short, and very little deterioration of the traffic-handling capacity of the circuits from this cause has been observed.

Endeavours have been made to correlate the field changes with meteorological conditions, but without success. Since it is concluded from general observation that the propagation of ultra-short waves over non-optical paths is due to diffraction and refraction as distinct from reflection from ionized layers in the upper atmosphere, it is to be expected that some dependence on meteorological conditions would be observed. The failure to establish such a relationship is probably due to the meagre data available on the conditions obtaining over the path, as meteorological data are available for the terminal points only. It is interesting to note that during the period of intense sunspot activity in the early part of 1938 no departure from the normal propagation conditions was observed on the Chaldon–Guernsey link. On the 60-Mc./sec. circuit, however, the range of fields was 78 db. to 0 db. (relative to 1 μV/m.) in the spring of 1938, compared with 50 db. to 0 db. in the spring of 1937. On the 37·5-Mc./sec. circuit the range of fields was the same in both years, viz. 70 db. to 0 db.

In connection with the investigations of propagation and interference the Post Office produced a portable field-strength and voltage measuring set. The set (see Fig. 3 on Plate 1, facing page 8) is a superheterodyne working on an intermediate frequency of 450 kc./sec., and it has a working range of from 150 kc./sec. to 25 Mc./sec. (2 000–12 m.). The calibration of the set is checked by adjusting the gain to produce a known output from the thermal noise in the first tuned circuit when tuned to a frequency of 240 kc./sec.

The apparatus is arranged for measuring voltages and field strength, the latter with either a frame or vertical rod aerial. The frame aerial may be rotated in a " plug-in " socket, providing simple direction-finding facility. The output circuit includes a meter and telephones with a short time-constant detector for listening and a long time-constant for measurement purposes. The latter conforms to the recommendations of the C.I.S.P.R.* for interference measurements. Automatic gain control is provided for short-wave listening. The receiver sensitivities are approximately 10 μV/m. for voltage measurements and 10 and 200 μV/m. for field-strength measurements, using the vertical-rod and frame aerial respectively. A total attenuation of 90 db. is provided in the intermediate frequency.

The receiver has proved very useful, and the design has been freely communicated to manufacturers, with the result that there are now a number of sets of similar type available on the market.

In view of the work which had been in progress on ultra-short waves it was decided to develop a similar type of set for measurements in this range. As a basis the previously-described superheterodyne commercial receiver was taken, the crystal-controlled beating oscillator substituted by a stable variable-frequency oscillator, and an attenuator provided in the intermediate-frequency circuit of 100 db. in 5-db. steps (see Fig. 4 on Plate 2).

The frequency range of the receiver is from 20 to 75 Mc./sec., and its sensitivity is 10 μV/m. and 2 μV/m. for voltage and field-strength measurements respectively. For voltage measurements a length of co-axial cable approximately 10 ft. in length is used to apply the unknown voltage to the measuring set. The impedance at the input end of the cable is arranged to be greater than 1 000 ohms with one terminal at earth potential.

For field-strength measurements a rod aerial is used. This may be fixed in a vertical or horizontal direction. With the horizontal aerial the receiver may be used for approximate direction-finding purposes.

The output circuit is similar to that of the 2 000–12 m. set. Both sets must of course be calibrated initially from some standard source of voltage and field. On the lower-frequency set this is done by means of a standard-type field-strength-measuring set provided with a comparison oscillator and attenuator. The ultra-short-wave set can be calibrated in the same way or by means of a computed field set up by a horizontal loop aerial carrying a known current, a method introduced by the National Physical Laboratory. The novelty feature of these sets is of course the application of the thermal noise method of calibration to these higher frequencies. The facility of checking the calibration without the use of a separate comparison oscillator simplifies the set and increases its portability.

One of the most serious sources of interference on ultra-short waves is the ignition systems of internal-combustion engines. This subject was dealt with in a recent paper* read before this Section.

Experience indicates that interference with commercial traffic can be appreciable if the source of interference is within $\frac{1}{4}$ mile of the receiving aerial.

Vertically-polarized receiving systems are much more susceptible to ignition interference than horizontally-polarized systems. In one typical case, where a road passed before the receiving aerial, a reduction of interference by 25 db. was attained by changing over the transmission from vertical to horizontal polarization.

Qualitative observations indicate that ignition interference is considerably reduced as the wavelength is reduced from 5 m. to 2 m., and this is an incentive to pressing forward the development of equipment for the use of these shorter waves.

In radio-telephone circuits used for public traffic some degree of privacy is desirable to hinder accidental or intentional eavesdropping. Most types of privacy equipment in use for longer-distance services are relatively expensive, and endeavour has been made to produce something simpler but effective. Where a number of radio-telephone circuits exist over a route it has been found possible to employ a channel-switching privacy system. This system changes the line circuit associated with a particular radio circuit every few seconds, with the result that a receiver tuned to the radio circuit produces an output consisting of jumbled scraps of several conversations.

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* Comité International Spécial des Perturbations Radiophoniques.

* A. J. Gill and S. Whitehead: "Electrical Interference with Radio Reception," *Journal I.E.E.*, 1938, vol. 83, p. 345; and *Proceedings of the Wireless Section*, 1938, vol. 13, p. 209.

In one system of this kind in actual service provision is made for switching six go and return radio channels between six 4-wire telephone circuits.

Automatic telephone type uniselectors are employed for the actual switching operation. The uniselectors are fitted with bridging wipers so that all circuits are short-circuited while the change-over is taking place. Synchronism of the switching at the two ends of the radio channels is obtained by the use of a single control tone operating over a separate radio channel to and from the controlling station. This tone, operating through relays, energizes the drive magnet of all the uniselectors. Chain contacts on the selectors cause the tone to be returned to the control point only when all the drive magnets have been energized. The return tone after passing through a timing circuit cuts off the original source of tone so that all drive magnets are released simultaneously and the wipers step one contact. The process is then repeated, the frequency of operation being determined by the setting of the timing circuit. The operation of the switches is normally imperceptible to persons talking over the circuits.

Leaving the subject of ultra-short waves, I now propose to say a few words on a development relating to frequency measurements and piezo-electric quartz crystals.

The improvements affected in frequency standards during the past 15 years have been considerable, and whereas a precision of measurement of ± 100 parts in 10^6 was exceptional in 1923 the corresponding orders for 1928 and 1933 were ± 10 parts and ± 1 part in 10^6 respectively. To-day it is possible to measure to ± 1 part in 10^7, and in the near future it will be possible to work to ± 1 part in 10^8.

The development of methods of precision measurement of frequency in the Post Office became necessary because the Post Office is the authority responsible for the allocation of wavelengths in this country and it had to possess means to determine whether stations are working on their allotted frequencies, and when interference arose between stations it had to be in a position to determine which station was off its frequency. Other requirements, however, have since led to advances in equipment beyond those demanded for ordinary station measurements. The Post Office standards comprise two valve-maintained elinvar forks working at 1000 c./sec. and one quartz-controlled oscillator working on 1 000 kc./sec., all of which are maintained in conditions of constant temperature and barometric pressure. The provision of a second quartz-controlled oscillator of a different type working on a frequency of 100 kc./sec. is in hand.

The frequencies of the oscillators are determined daily in terms of mean solar time.

The Post Office standards, which are housed at the Dollis Hill Experimental Station, are compared at monthly intervals with the standard of the National Physical Laboratory, the comparison being effected by means of the 1 000 c./sec. transmitted as a modulation from the Teddington transmitter on a carrier of 396 kc./sec. The agreement between Teddington and Dollis Hill is normally within ± 1 part in 10^7. On occasions, when local conditions of reception permit, opportunity is taken to compare the local standard with the calibration signals transmitted from Washington by the Bureau of Standards. Again the agreement between the two is within ± 1 part in 10^7.

Frequency-multiplying and measuring equipment associated with the standard enables the ultimate accuracy to be translated to any frequency in the spectrum up to 75 Mc./sec. The method employed for such translations have been already described elsewhere and will not be repeated. The equipment used for this purpose at Dollis Hill is contained on 12 bays of racks and includes comparison signal oscillators for field-strength measurements, audio-frequency amplifiers for dealing with incoming land-line signals, and a long-wave receiver for time-signal reception. Although the present precision has been obtained by means of elinvar tuning forks it seems probable that advances to higher precision in the future will be made by means of quartz oscillators. The advantages of quartz are:—

(*a*) The lower frequency/temperature coefficient it is possible to obtain with quartz, as compared with up to ± 10 parts in 10^6 per 1 deg. C. for the fork, depending on the alloy.

(*b*) The comparatively simple mounting system which is possible with the crystal.

(*c*) The absence of any serious ageing effect. In elinvar, ageing occurs over a period of many years with consequent slow frequency drifts.

The crystal to be used as a standard should be of one of the zero frequency temperature-coefficient type, and its mode of vibration must be such as to permit of a nodal plane suspension. Three main types of crystal are therefore available—the ring operating on an overtone of a circumferential mode, the bar oscillator, and the plate. The upper frequency limit of the first two types is about 100 kc./sec. and of the last type about 1 000 kc./sec.

The 1 000-kc./sec. crystal used as a standard is a rectangular plate of sensibly zero frequency temperature-coefficient. It oscillates in a shear mode and is clamped in the nodal plane mounted in a partially evacuated holder, a double air-gap being employed. The drive circuit employs a pentode drive stage resistance-coupled to a pentode buffer stage; a number of independent 75-ohm outputs are available from an output transformer. The power supplies, obtained from floating batteries, are stabilized.

The frequency/temperature curve of the crystal is given in Fig. 5, from which it will be observed that the average coefficient of the mounted crystal over the temperature range 19° to 55° C. is only 11 parts in 10^8 per deg. C.

The frequency-standard equipment installed at Dollis Hill is not now used for checking the frequencies of transmitting stations, except in the case of transmitters sending out standard frequency transmissions or other special emissions such as international comparisons of standards. The work of checking normal transmissions increased so much that it became necessary a few years ago to establish a separate station for the purpose, manned throughout the 24 hours. Until recently this station was at Colney Heath and formed part of St. Albans Telegraph Receiving Station. Within the last few months it has been transferred to more commodious quarters at Baldock. The function of the station is to determine where the error lies in the cases of interference where British stations are involved, and also whether British stations are conforming to international regulations by maintaining the emitted wave within the limits of frequency tolerance. This work does not demand measurements of the maximum precision now possible. The equipment at Baldock, therefore, is not designed to give such a continuously high standard of precision as that at Dollis Hill, but means are provided for immediate comparison with Dollis Hill by land-line connection.

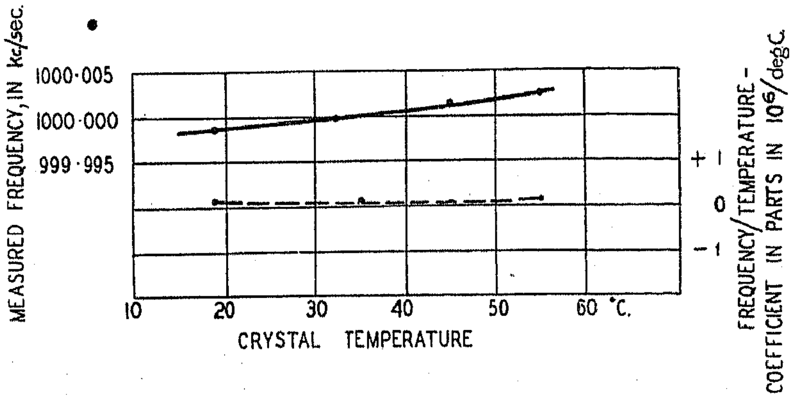


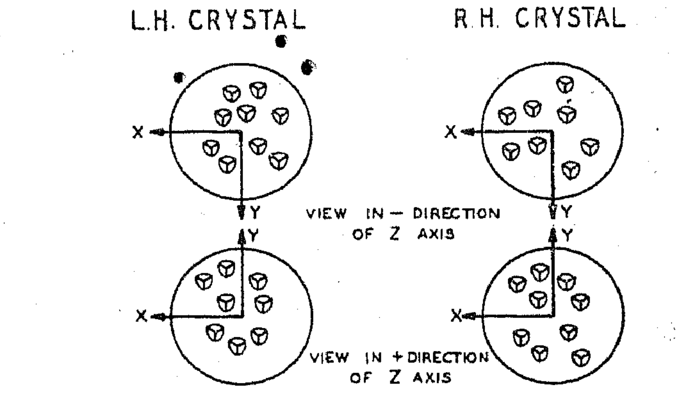
Fig. 5.—Frequency/temperature curve of 1 000 kc./sec. standard crystal mounted in 6 A holder.

A great stimulus has been given to the production and use of quartz bars by recent developments in carrier telephony. Whereas the whole of the Post Office requirements for crystal oscillators for the purpose of frequency stabilization can be counted in hundreds, the demand for crystal resonators for the full equipment of a single co-axial cable may exceed 10 000.

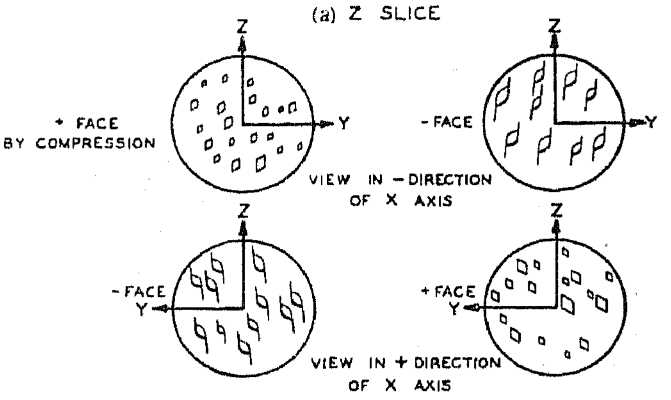
The crystal laboratory at Dollis Hill is concerned with the development of production technique for quartz plates for frequency standards, sub-standards, fixed and mobile transmitters, and crystal filter resonators, and it may be of interest to say a few words about the work of this laboratory.

The first problem concerned with crystal production is the selection and grading of the raw material. Unfortunately, the crystal suffers to a considerable extent from two main defects, "twinning" and internal flaws, and the presence of either fault precludes the use of the crystal for the above-mentioned piezo-electric purposes. Flaws can usually be detected by careful examination, but although twinning (a lack of homogeneity in the molecular structure) may be apparent from natural etch patterns on the crystal faces, or from discontinuities in the texture of the face (see Fig. 6 on Plate 2), this is not always the case and recourse to cutting and acid etching is usually necessary before the quality of the material can be determined.

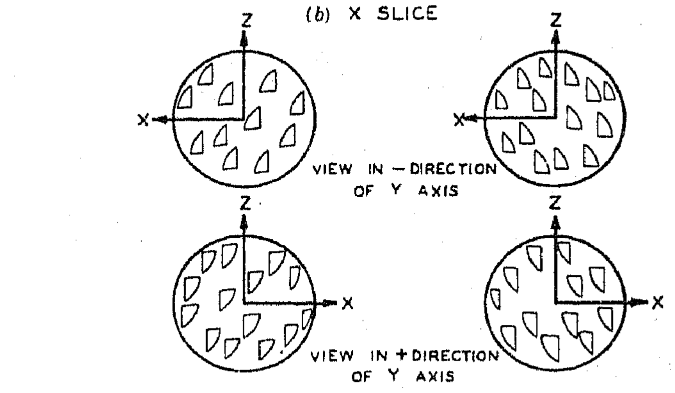
A comprehensive analysis of twinning faults has been made at Dollis Hill, and etching technique has been developed for the determination of the presence of the three twinning forms, optical, electrical, and combined electrical and optical. The characteristic etch patterns for untwinned and the three varieties of twinned left- and right-hand quartz in the X, Y, and Z planes for both viewing directions are shown in Fig. 7. The X-plane etch patterns for untwinned and for electrically twinned left- and right-hand quartz for both viewing directions are illustrated by the photo-micrographs in Fig. 8 (see Plate 3).



(a) Z SLICE



(b) X SLICE



(c) Y SLICE

Fig. 7.—Characteristic etch patterns on the X, Y, and Z planes of R.H. and L.H. quartz.

The best supplies of natural quartz consist of large crystals having well-defined faces and whose crystallographic axes can be readily identified. There is, however, a large amount of material available in which the natural faces have been partially or completely destroyed. To permit the use of this inferior material methods have been developed for identifying the crystallographic axes in such samples when not even a portion of one natural face exists.

The performance of the apparatus employed for the determination of the Z axis of a Z slab is clearly demonstrated in Fig. 9 (see Plate 4), which shows the effect of decreasing inaccuracy of alignment on the interference patterns.

Machines have been designed for the speedier and more accurate cutting of crystals. One of these machines is shown in Fig. 10 (see Plate 5), and the accuracy and economy of the cutting process is clearly demonstrated in Fig. 11 (see Plate 8), which shows photographs of a Z slab which has been sliced into X plates. In Fig. 11(a) the plates have not been removed from the glass disc to which they are cemented by special wax, while in Fig. 11(b) they have been removed and cleaned.

The plates of quartz are finished by lapping processes, and a large saving of time and labour can be effected if the plates cut on the machine are very close to the final dimensions.

Mention has already been made of plates of sensibly zero frequency temperature-coefficient. In these plates the angle of cut is so adjusted that the resultant of the individual coefficients of e, c, and ρ, in the solution of the equation $f = \frac{1}{2e}\sqrt{\frac{c}{\rho}}$ [which gives the frequency of plate in terms of e (thickness), c (elastic coefficient), and ρ (density)] is reduced to zero. In fact zero-coefficient crystals can be produced in the continuous range 50 to 25 000 kc./sec., and frequency/temperature curves of four representative plates having frequencies of 100, 2 750, 4 767, and 15 482 kc./sec. are given in Fig. 12. It should perhaps be pointed out that the attainment of the absolutely zero coefficient is difficult and individual attention on each plate is necessary. The curves shown are for plates which have not received this individual adjustment.

The production of plates of frequencies greater than about 10 Mc./sec. is one which calls for a very high degree of skill. The plates are extremely fragile, a zero-coefficient plate of frequency 20 Mc./sec. may have a thickness of only 0·12 mm., and a high degree of face parallelism is essential for satisfactory oscillators. Plates of frequencies up to 25 Mc./sec. have been made, but the

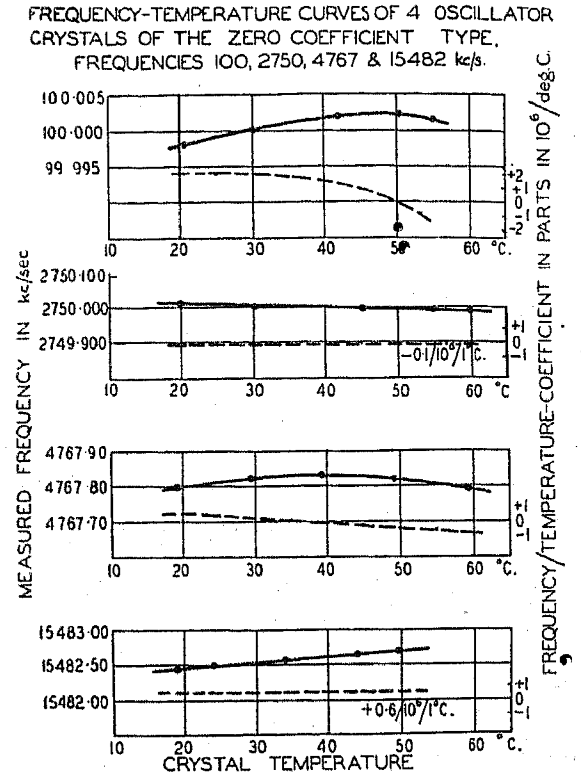


Fig. 12.—Frequency-temperature curves of 4 oscillator crystals of the zero-coefficient type. Frequencies 100, 2 750, 4 767, and 15 482 kc./sec.

Table 1

LIST OF FACTORS AFFECTING FREQUENCY OF 1 000-KC./SEC. CRYSTAL OSCILLATOR, ARRANGED IN ORDER OF IMPORTANCE

Factor	Artificial change of factor	Corresponding frequency change	Method of stabilizing factor	Estimated residual change of factor	Corresponding frequency change
Cathode-heater supply voltage	± 5 %	∓ $3·5/10^8$	Compensated mains transformer	< ± 0·25 %	∓ $1·7/10^9$
Anode supply voltage	± 5 %	± $3·5/10^8$	Compensated mains rectifier and stabilovolt	< ± 0·1 %	± $0·7/10^9$
Temperature of crystal and holder ..	± 1° C.	$1/10^7$	Thermostatically-controlled oven	< ± 0·01° C.	< ± $1/10^9$
Grid resistor	1 MΩ to 5 MΩ	$1/10^6$	Good-quality component	< ± 1 %	< ± $1/10^9$
Grid capacitor ..	20–30 μμF	± $7/10^6$	Good-quality components, thermostatically controlled	Negligible	
Valve replacement ..	Another of same type	$7/10^7$	Matched valves available	Negligible	
Load changes	Extremely wide	< $1/10^7$	Buffer stage	Negligible	
Anode-circuit tune (normal value 227 μμF	1 μμF	$1/10^8$	Thermostatically controlled	Negligible	
Mechanical shock and tilting of mounted crystal	Excessive	< ± $2/10^7$	Unlikely to occur in practice	Negligible	

commercial limit is considered at the moment to be about 20 Mc./sec.

An interesting application of the high-precision quartz oscillator has been in connection with common-wave broadcasting. At the request of the British Broadcasting Corporation the Post Office undertook to provide a number of quartz oscillators in the range 668 to 1 149 kc./sec., capable of maintaining a frequency constancy of ± 1 part in 10^7. As a preliminary to this work a careful investigation was made into the effects of variation of a number of circuit components and of supplies in the frequency of a 1 000-kc./sec. crystal drive. The results of the investigation and the methods adopted to avoid the effects of the variations are given in Table 1.

A number of the crystals have been completed and brought into use. Three crystals of frequency 1 149 kc./sec. have been employed to drive the Scottish National, Northern National, and London National transmitters. Methods of comparing the frequencies of these crystals have been developed by the British Broadcasting Corporation, to whom I am indebted for the results of tests. The crystal at the North National station (Moorside Edge) has been regarded as the reference crystal, and an output from this crystal is subdivided to give a frequency suitable for land-line transmission. This reference frequency is then transmitted by land line to the London National and Scottish National transmitters, where by multiplying apparatus it is reconverted to 1 149 kc./sec. and is available for direct comparison with the local carriers. At Brookmans Park, for example, an output from the local crystal is combined with the incoming reference frequency; the resultant beats are automatically recorded, and the frequency difference between the two drives may be observed directly from the chart record.

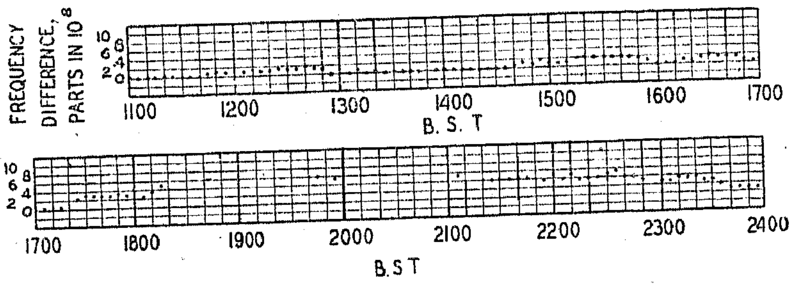


Fig. 13.—Frequency difference between Brookmans Park National transmitter and North National transmitter, 1 149 kc./sec., long-period stability, 18th June, 1938.

The Brookmans Park record for the period 1100 to 2359 G.M.T. on the 18th June, 1938, has been analysed and the results are given. It should be pointed out that during the period of test no adjustments were made to the crystal. The frequency difference in parts in 10^8 between the two drives have been plotted at 5-minute intervals, except for short periods when the record was marred by line disturbances (see Fig. 13). An additional analysis showing the frequency difference at intervals of 25 seconds over a 10-minute period is given in Fig. 14.

From Fig. 13 it will be observed that for periods of one hour or more the frequency difference was negligible, i.e. less than 1 part in 10^8, and that the total separation was only 6 parts in 10^8. These results indicate clearly that it is practicable to achieve the required frequency stability for common-wave broadcasting by the use of rigid oscillators.

Finally, I should like to say a few words about long-distance short-wave telephony, with particular reference to the transatlantic service. While short-wave radio can provide telephone links spanning many thousands of miles at relatively low cost, such circuits are not always effective and free from distortion. Difficulties arise from the nature of the medium responsible for the transmission of these waves. This medium, as is well known, consists of fairly sharply defined regions of high ionization density situated at heights of from 100 to 500 km. above the earth's surface. The layers are subject to variation of height and density which are dependent on the ultra-violet radiation of the sun. Thus, not only is the received field subject to hour-to-hour variations over a wide range but in addition the irregular nature of the transmitting medium gives rise to multiple-path transmission. The multiple-path transmission produces interference at the receiving point between signals which have traversed different ether paths and which have been subjected to different and varying time delays. The time delay between the various components accepted by the receiver is the cause of the distortion and apparently changing audio-frequency response characteristic often noticeable on short-wave circuits.

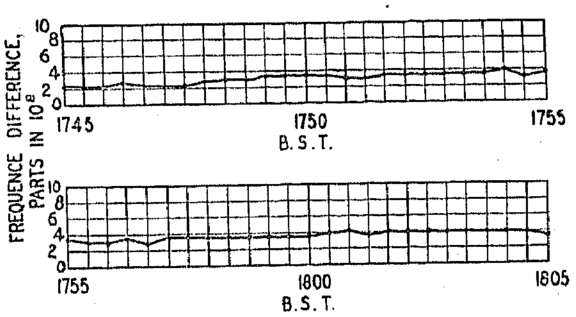


Fig. 14.—Frequency difference between Brookmans Park National transmitter and North National transmitter, 1 149 kc./sec., short-period stability, 18th June, 1938.

At times also the medium, as the result of some abnormal activity of the sun, loses its reflecting properties and signals may fall to values so low as to be useless or may even disappear for days. These disturbances, when they occur, generally affect all short-wave radio circuits simultaneously, but they are usually more severe and more prolonged over routes passing near the polar regions. The transatlantic service is particularly liable to such troubles, which are all the more serious in this case because it is the busiest long-distance service in the world. Correlation has been established between times of maximum disturbance of the radio circuits and maximum sunspot activity, and the actual disturbances are accompanied by magnetic storms. The next sunspot maximum is due to occur in the years 1939–40, and for the last few years the possibility of limiting the effects of that anticipated disturbed period has been studied by the American Telephone and Telegraph Co. and the Post Office. The previous bad period occurred when short-wave telephony was only commencing and the main load was carried by the long-wave circuit, which is unaffected by magnetic storms. Now, however, the main traffic is carried by the four short-wave circuits, and the long-wave circuit does not afford an adequate standby.

In order to reduce as far as possible the deterioration produced by periods of magnetic storm two improvements are necessary, viz.

(1) To increase the received field strength so that it remains above the level of noise by the largest possible margin, in order to reduce as far as possible the extent and duration of fades.

(2) To minimize by some means the effect of wave interference.

As regards (1), the transmitter power at present in use is already approaching the economic limit, and antenna directivity of the fixed type has probably been exploited to the greatest useful extent. The solution has therefore been sought in the use of a single-sideband system of transmission. With regard to (2), until recently there has seemed to be no escape from wave interference, but recent work in America suggests that these effects may be alleviated by the use of a receiving system which is capable of separating the various rays arriving at different angles to the horizontal, and using these as separate factors for diversity reception. This system has been proposed by engineers of the Bell Laboratories and designated the M.U.S.A. system (Multiple Unit Steerable Antenna). Receiving systems of this type for use on the Transatlantic Telephone Service are at present under construction in England and America.

The advantages of single-sideband working on short waves were touched on by Dr. R. Bown in his recent Lecture* before this Section, when he mentioned that, in addition to the saving in carrier power and the reduction in noise due to the reduced band width required, there was also an improvement in quality due to reduced distortion. The gains due to carrier reduction and lessened band width can be readily assessed as being equal to 6 db. and 3 db. respectively. The gain due to lessened distortion cannot be so readily assessed, but the total improvement in signal/noise ratio due to the use of single sideband for a given peak power at the transmitter may be taken as equivalent to from 9 to 12 db. (in other words equal to raising the transmitted power from 8 to 16 times) over the double-sideband system.

The saving in the width of the frequency band occupied by a single channel makes it possible to place two speech channels in a frequency allocation which has previously carried only one double-sideband channel. The extra speech channel is obtained at appreciably less cost than is involved in setting up an additional double-sideband transmitter and receiver. Double-channel working has been in operation experimentally on the London-New York circuit, and it may be of interest to give a brief description of the receiver used by the Post Office—the American Telephone and Telegraph Co.'s receiver has already been described.

Fig. 15 shows a frequency spectrum for the dual-channel transmission. By arranging that there is a separation of at least 2·75 kc./sec. between the channels the intermodulation products of the highest level fall in this range and so do not contribute to the channel-to-channel cross-talk. The possibility of using this vacant band for a telephone channel for service communication on lower modulation has been considered, but equipment for this purpose has not yet been fitted.

The layout of the receiver is shown in Fig. 16 (see Plates 6 and 7), and a block schematic diagram of the arrangements is given in Fig. 17. The receiver incorporates two frequency-change steps; the first intermediate-frequency band is from 594 to 606 kc./sec., and the second intermediate band is 100 to 106 kc./sec. The relatively high first intermediate frequency allows a discrimination of more than 70 db. to be obtained against the image channel approximately 1 200 kc./sec. away, while the relatively low second intermediate frequency allows a discrimination of more than 90 db. to be obtained against the adjacent channel. The frequency of the first beating oscillator in the receiver is electrically controlled, so that the frequency of the pilot carrier at the second intermediate frequency does not differ from that of a 100-kc./sec. crystal-controlled local oscillator by more than 10 cycles per sec. The frequency-control system is non-mechanical in character, the frequency of the first beating oscillator being made to depend on the direct voltage applied to the suppressor grid of a high-frequency pentode control valve. The direct voltage is derived after rectification and smoothing from two low-frequency control tones, nominally at 4·9 kc./sec., which are made to diverge in frequency and amplitude as the reconditioned carriers depart from equality of frequency with the 100 kc./sec. crystal-controlled local oscillator.

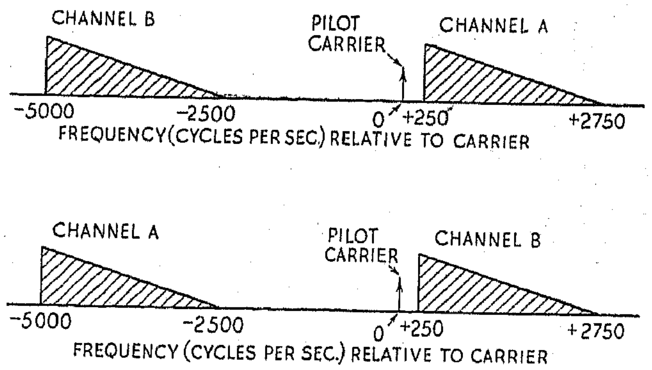


Fig. 15.—Frequency spectra radiated by dual-channel single-sideband transmitter.

The degree of frequency control is such that the locally generated carrier may be used at the detector without any noticeable degradation of speech quality. In practice, however, a reconditioned carrier is generally used.

The pilot carrier is selected at the second intermediate frequency by means of a narrow band filter incorporating 6 X-cut quartz plates arranged in two ladder filter sections (Fig 18). The effective band-width of this filter is about 120 cycles per sec. at a frequency of 100 kc./sec. (Fig. 19). By the use of beating-oscillator frequencies of 500 and 700 kc./sec. at the second frequency-changer, similar filters may be used to select the channels. The channel filters have a band-width of from 100 to 106 kc./sec. and incorporate 16 X-cut quartz plates

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* *Journal I.E.E.*, 1938, vol. 83, p. 395; and *Proceedings of the Wireless Section*, 1938, vol. 13, p. 259.

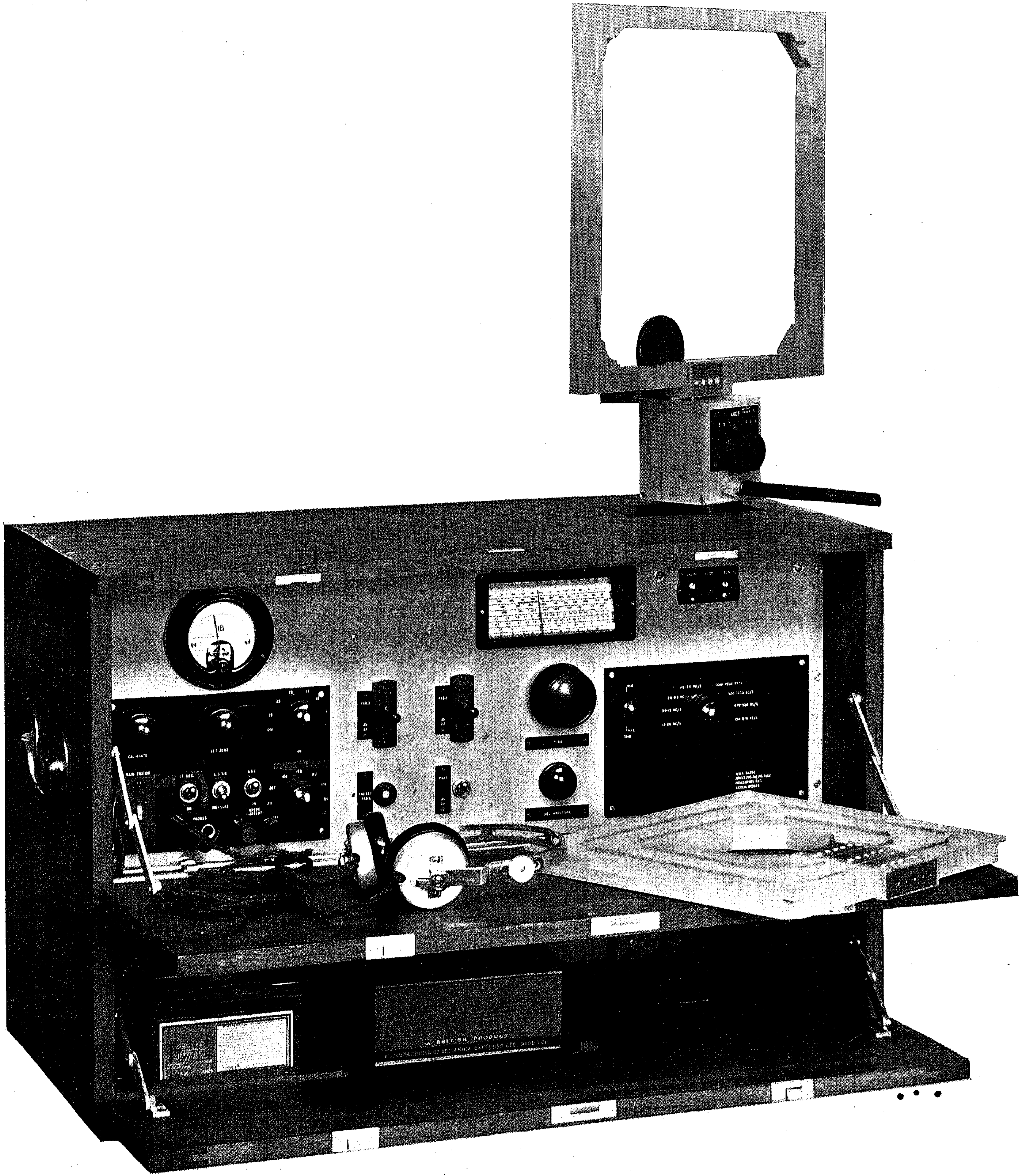


Fig. 3.—Wide-range portable noise-field and voltage measuring set, showing loop aerial for field-strength measurement and direction-finding on 150 kc./sec.–25 Mc./sec.

Plate 2

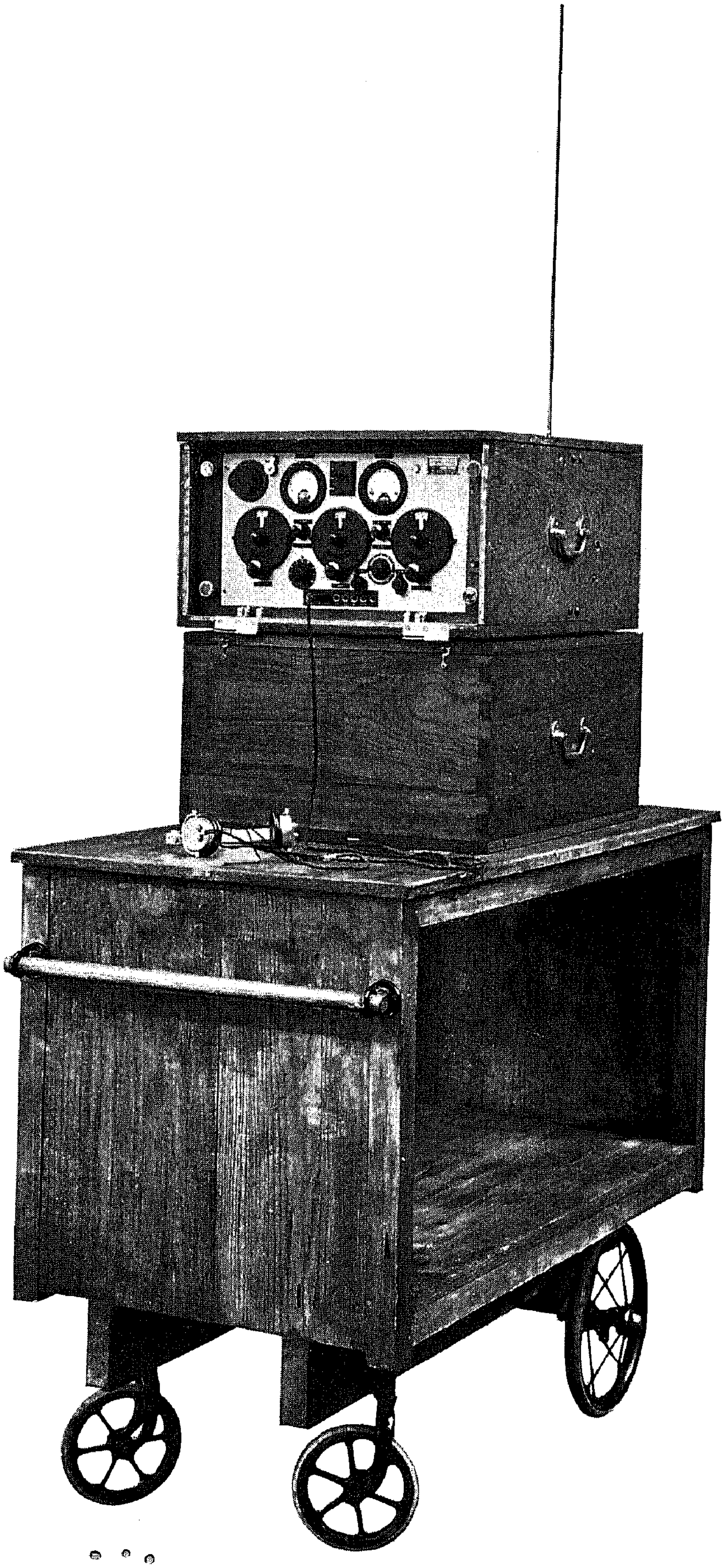


Fig. 4.—Ultra-short-wave field-strength measuring set.

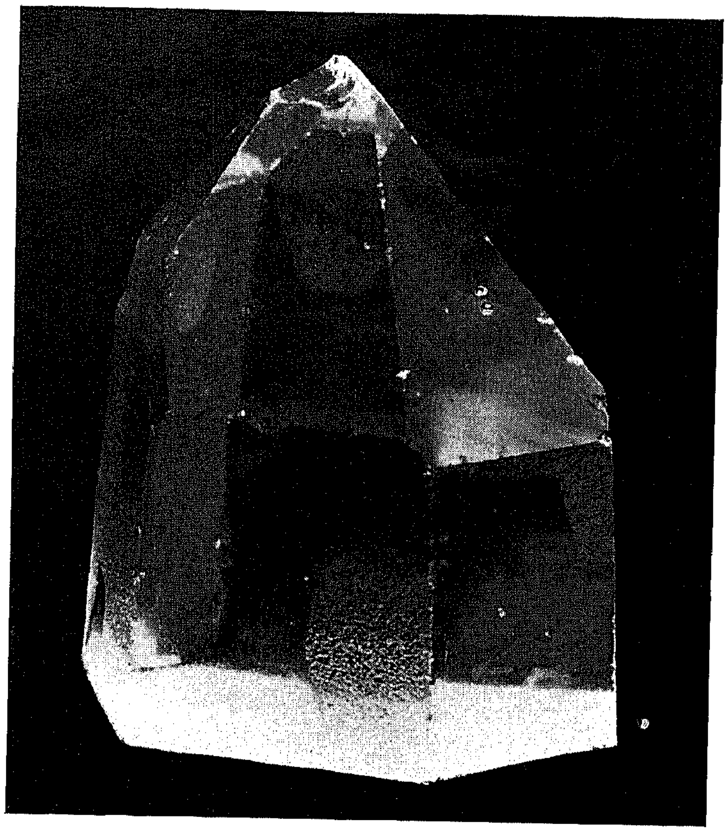


Fig. 6A.—Natural etch pattern on prism and pyramid faces.

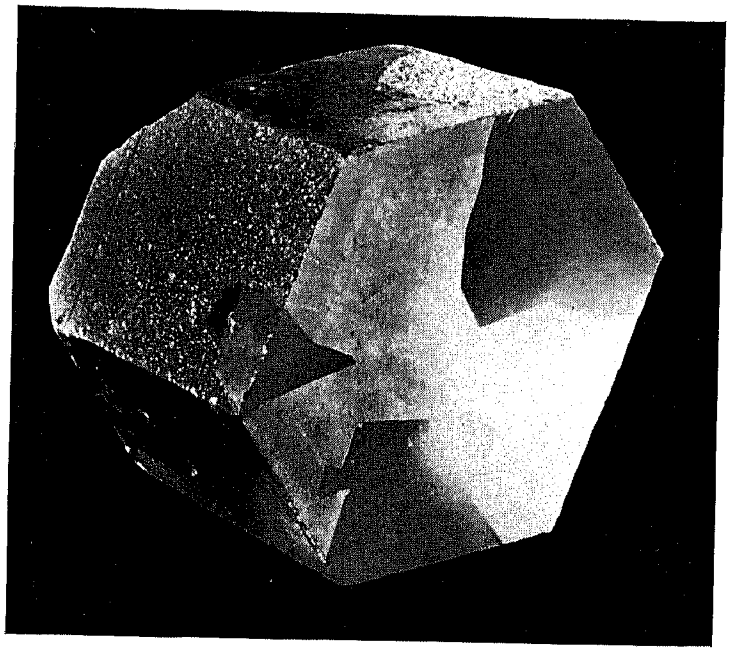
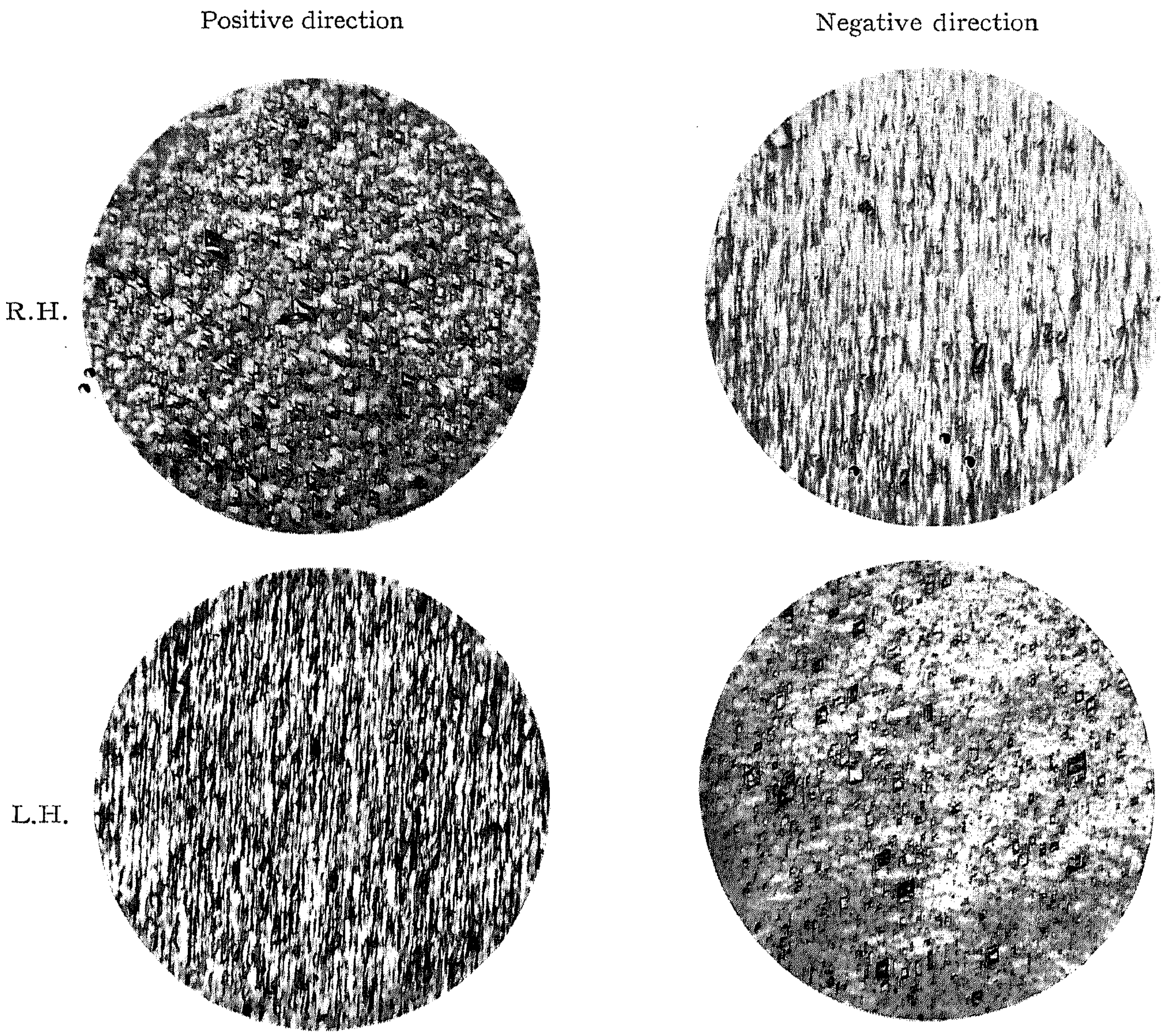
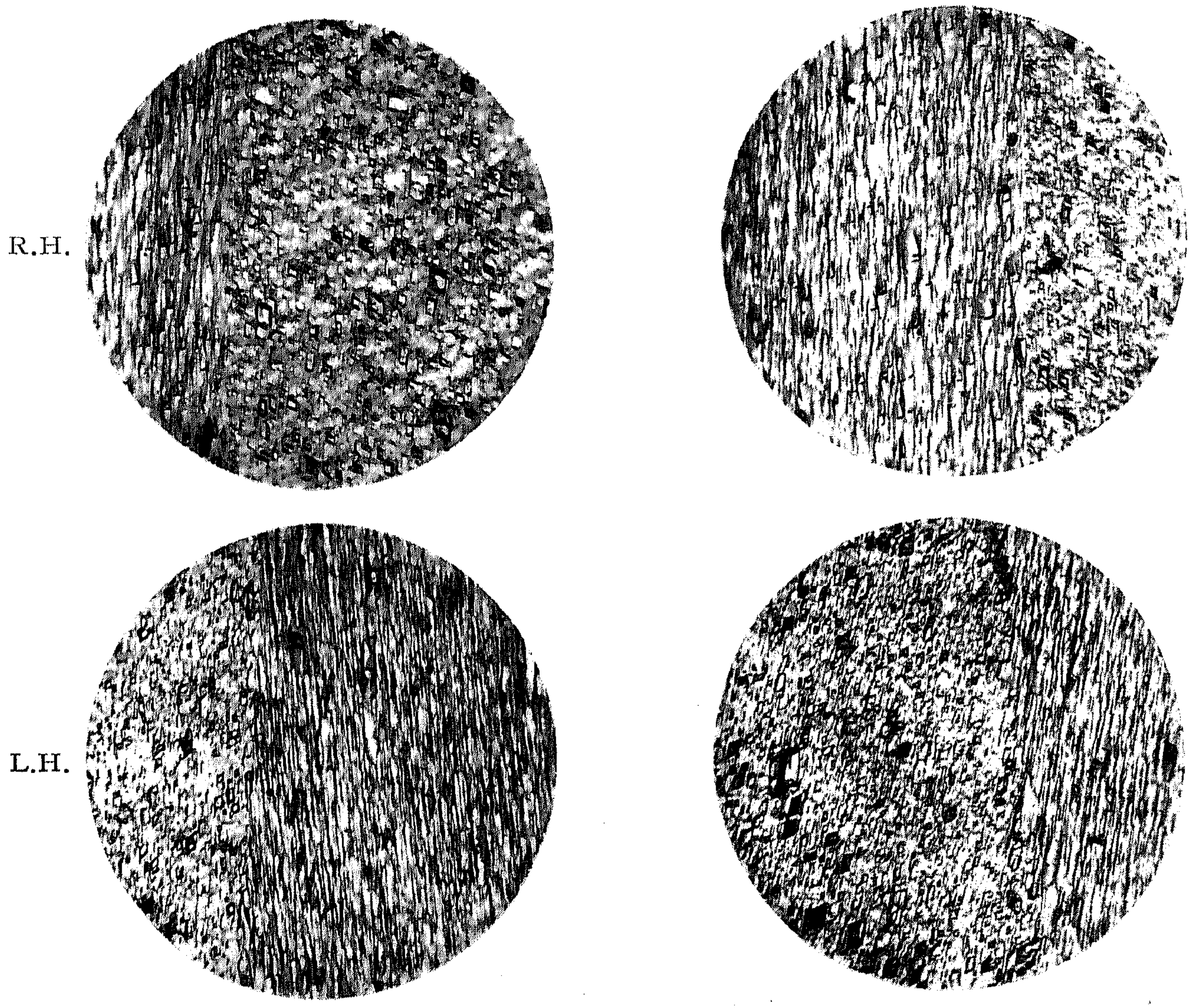


Fig. 6B.—Etch pattern on prepared Z plane of the crystal.



(*a*) Untwinned.



(*b*) Electrical twinning.

Fig. 8.—Etch patterns in X planes. Magnification 120 diameters.

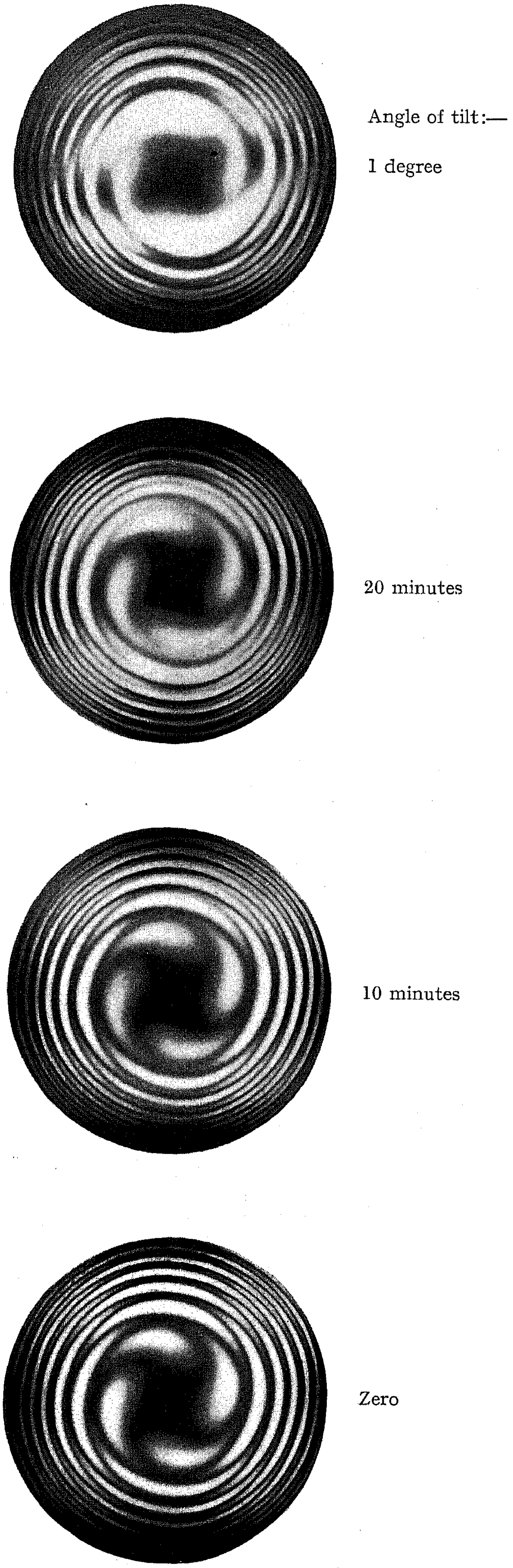


Fig. 9.—Interference pattern for a trued Z slab in polarized convergent monochromatic light.

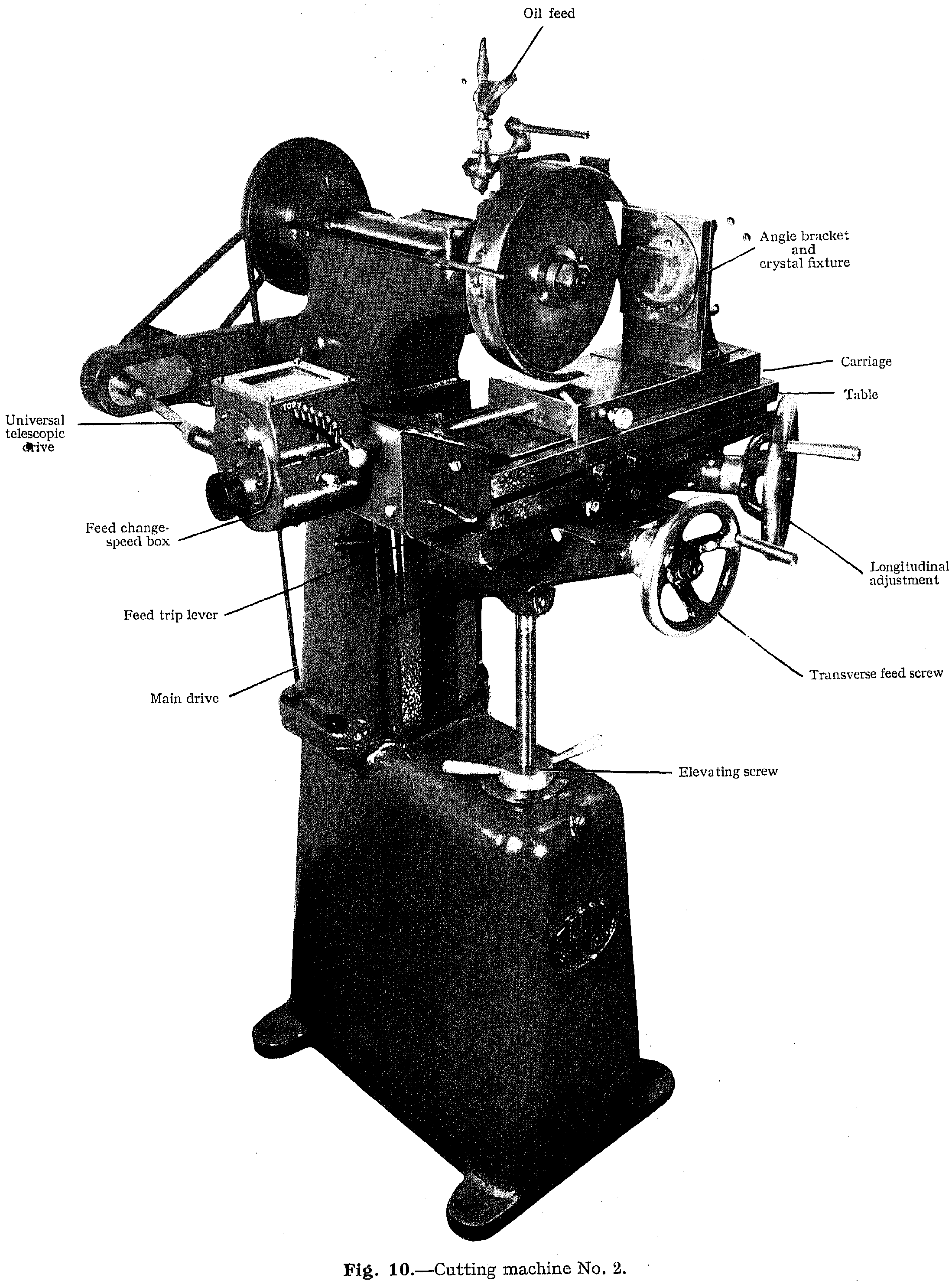
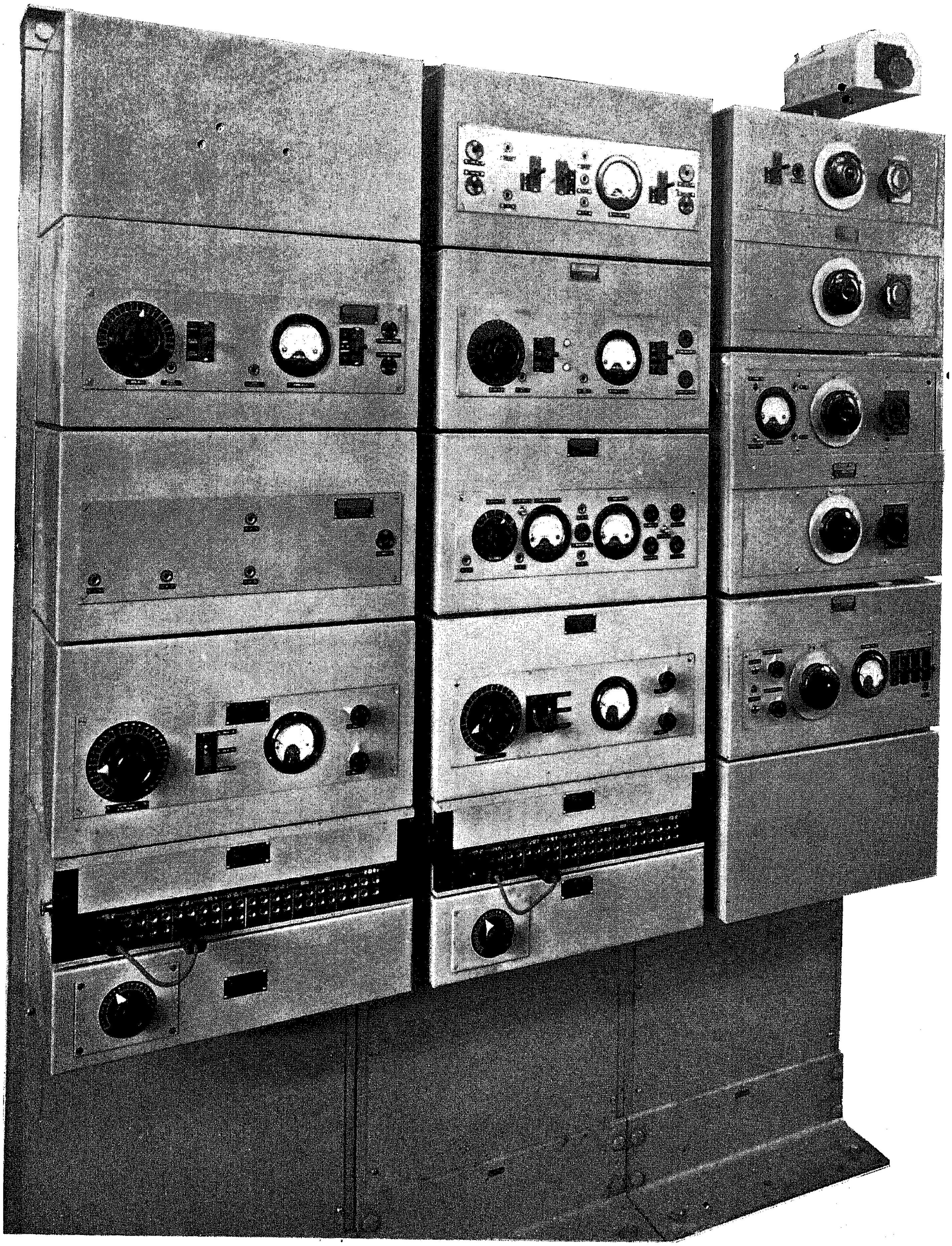
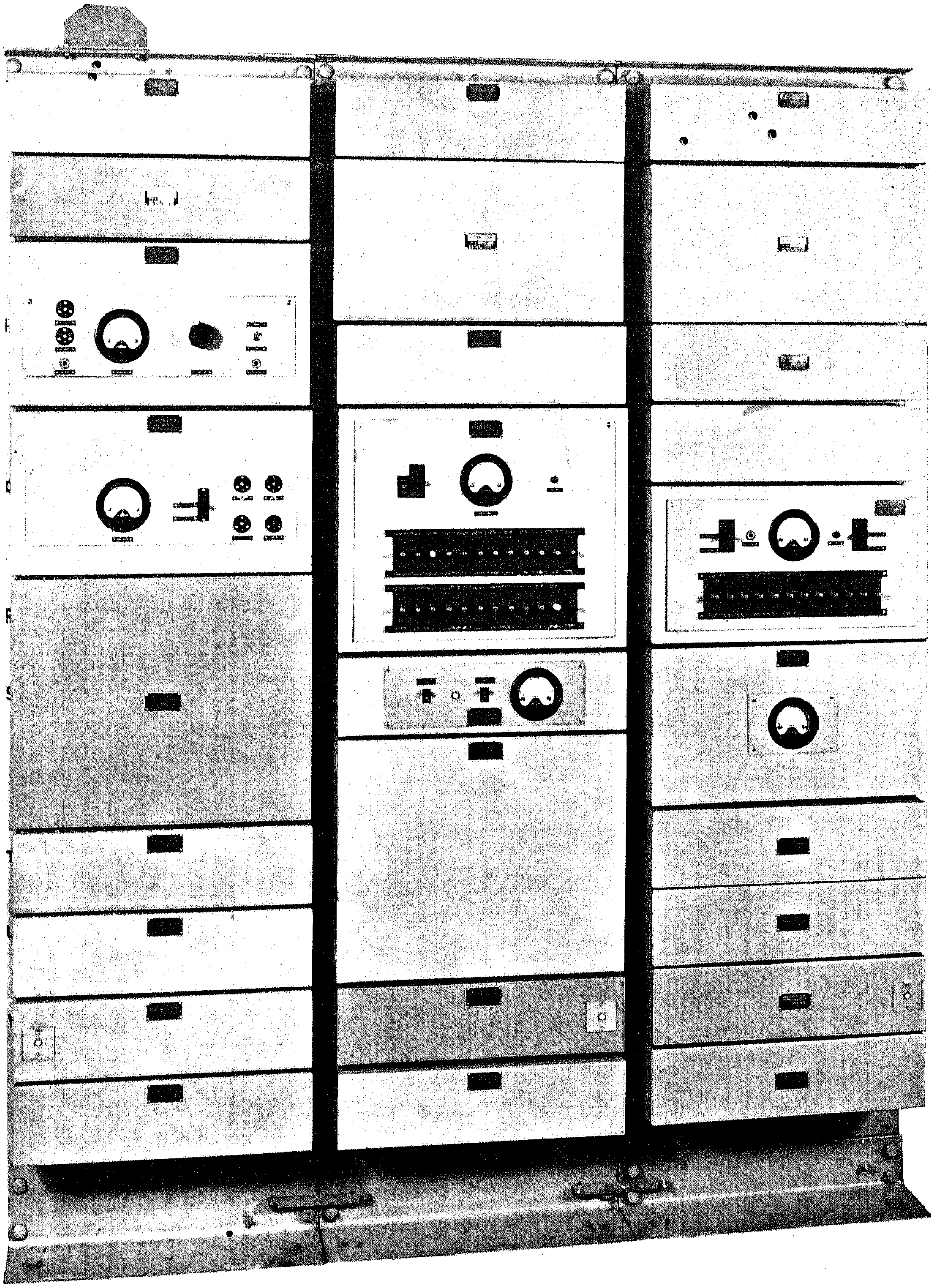


Fig. 10.—Cutting machine No. 2.



Front view

Fig. 16.—Dual-channel single-sideband radio receiver.



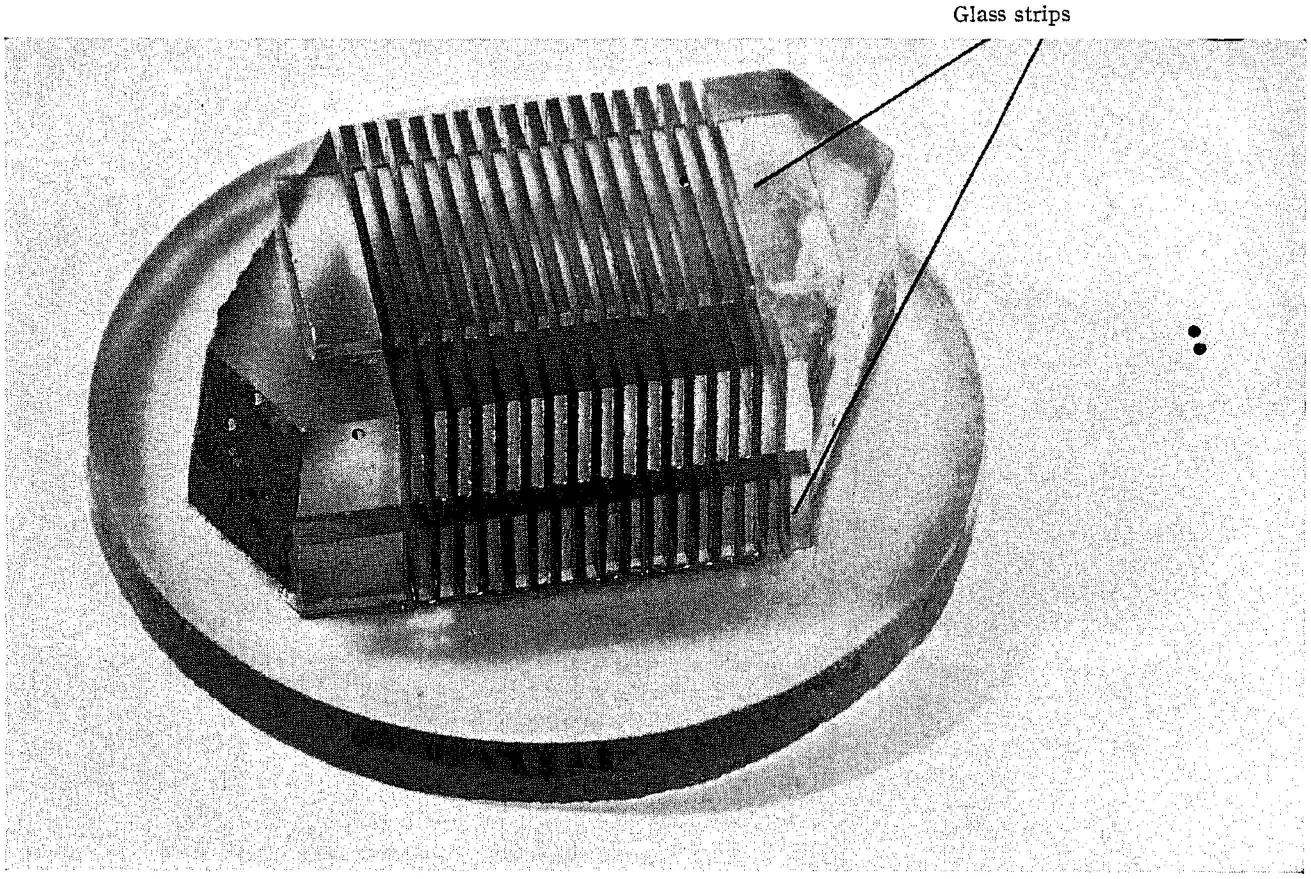
Antenna switch
Tag panel
I.F.1 filter
Frequency-control units 1 and 2
100-kc. osc. and 500 kc., 700-kc. harm. selectors
H.P. and L.P. filters
L.T. supply
L.T. rectifier

Tag panel
Channel filter
Carrier filter
Key, fuse, and meter panel
Supply panel
H.T. supply
L.T. supply
Line term^{n} panel

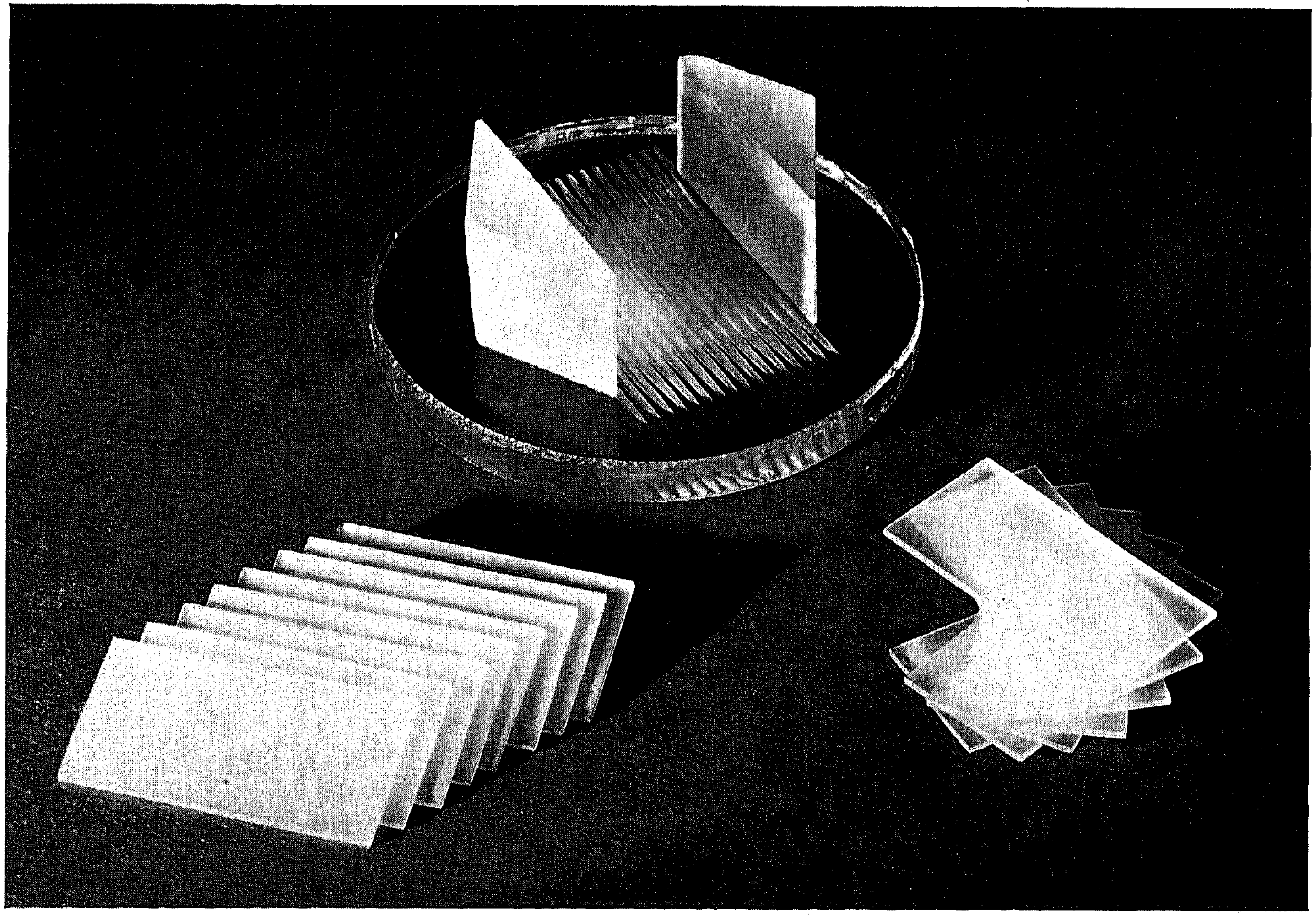
Tag panel
Channel filter
Carrier filter
Blank
Key, fuse, and meter panel
H.T. stabilizer
H.P. and L.P. filters
L.T. supply
Line term^{n} panel

Rear view

Fig. 16 (cont.).



(*a*) X plates in Z slab direct from cutting machine.



(*b*) X plates removed from Z slab and cleaned.

Fig. 11.—Stages in the preparation of X plates.

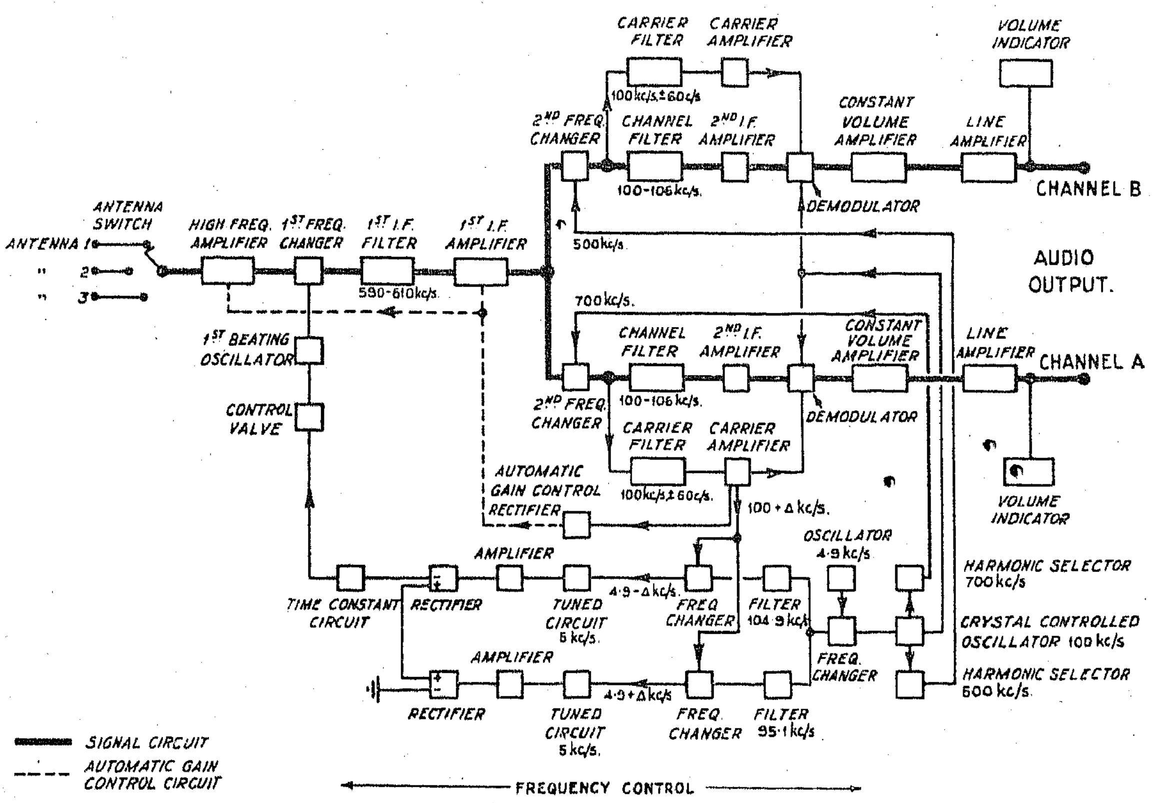


Fig. 17.—Block schematic of dual-channel single-sideband receiver.

arranged in four lattice sections (Fig. 18). The filters are hermetically sealed, since moisture tends to upset the transmission characteristics. The inductors included with the lattice sections make possible the relatively wide pass-band, while the shunt resistors, together with the balance-to-unbalance transformers joining the two halves of the filter, serve to prevent the transmission of current in phase along the arms of the filter. These longitudinal currents would otherwise impair the high values of attenuation obtained immediately outside the pass band (Fig. 19). Some audio-frequency equalization is incorporated in the receiver to correct for the slight increase in the insertion loss due to the filter near the carrier frequency, so that a music circuit with a band-width of 50 to 6 000 cycles per sec. can be provided when required.

The automatic gain-control system is of the delayed type operating from the pilot carrier. The automatic gain-control voltage operates on two signal-frequency stages and also on two stages of the first intermediate-frequency amplifier. Speech-level variations due to selective fading cannot, however, be completely eliminated by an automatic gain-control system operating solely from the pilot carrier. This difficulty has been overcome by the use of a constant-volume audio amplifier, the gain of which is varied automatically to maintain the speech volume at substantially constant level.

Turning now to the ray-diversity or M.U.S.A. system, a description of the general principle of the experimental system developed and installed at Holmdel, New Jersey, has been given by Dr. Bown.* As already stated, the American Telephone Co. and the British Post Office are each providing commercial systems of this kind for the transatlantic telephone service.

The new system will be much sharper in vertical directivity than the experimental model. The stations are being designed to have the same performance but differ to some extent in details. The British station is being built at Cooling Marshes, near Rochester, Kent, while the American station is being built at Manahawkin, New Jersey.

At Cooling the aerial system will consist of an array of 16 unit antennae placed along the great-circle path between the transmitter and receiver (see Fig. 20). The total length of the array will be approximately 2 miles, with the receiving station located at the end remote from the transmitter. The output from each unit antenna will be conveyed to the receiver by means of a separate buried coaxial transmission line.

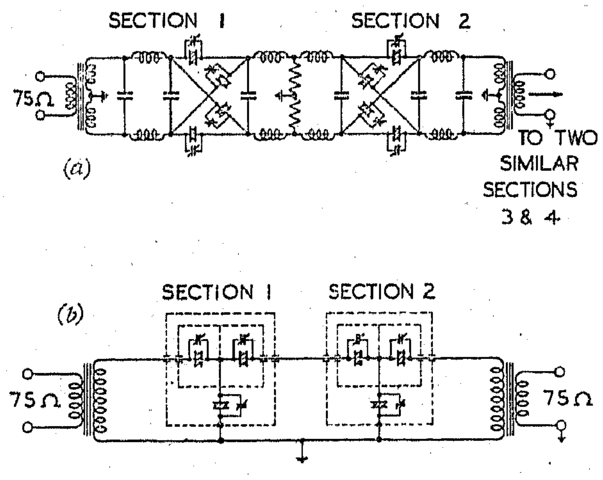


Fig. 18.—Circuit of carrier filter.

It will be obvious from Fig. 20 that if such a system is receiving a wave incident at an angle θ to the horizontal, then if the time of arrival at the receiver of the signal received by the antenna nearest the transmitter is taken as the datum the signal from the next antenna will arrive $\left(\frac{d}{v} - \frac{d\cos\theta}{c}\right)$ seconds earlier and from the the nth antenna $(n-1)\left(\frac{d}{v} - \frac{d\cos\theta}{c}\right)$ seconds earlier, if

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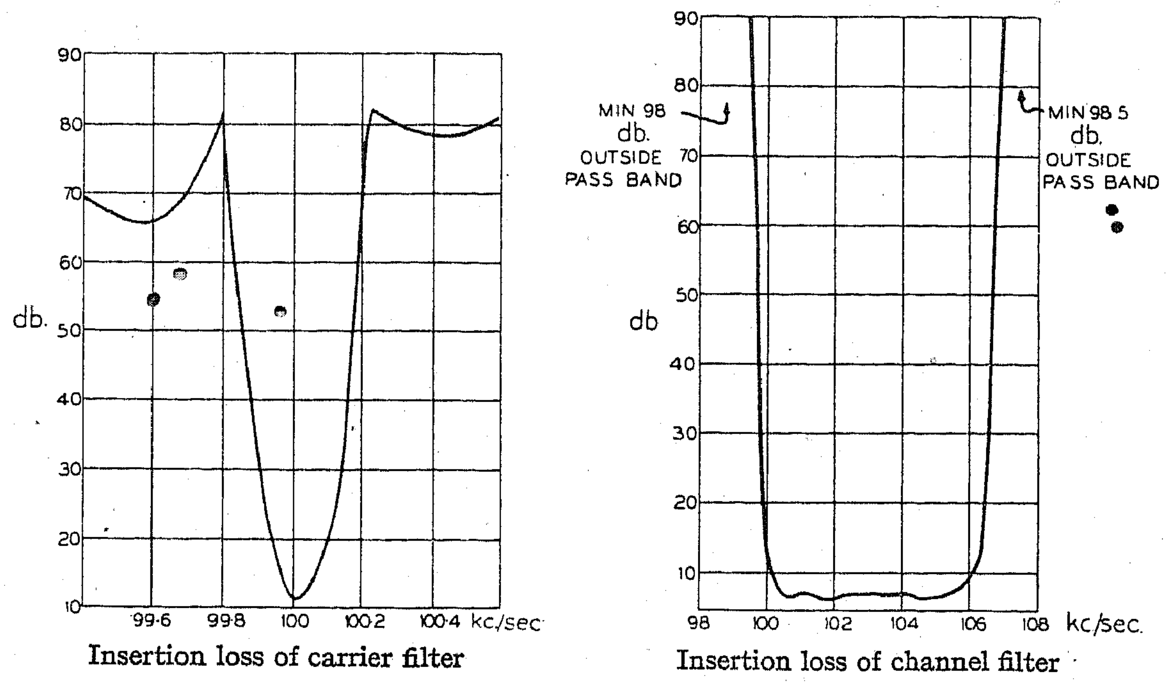
* Loc. cit.

d is the spacing between antennae, c the velocity of the wave in space, and v the velocity of the signal on the feeder.



Insertion loss of carrier filter

Insertion loss of channel filter

Fig. 19

If delay networks having these values of delay are inserted in the feeders then all signals arriving at a downward angle θ will be in phase at the receiver and if added will produce a maximum resultant equal to their arithmetical sum. Signals arriving at angles other than θ will not be in phase and, if added, will produce a vector sum less than their arithmetical sum. The correction by delay networks for a particular angle of incidence will hold for any frequency. Alternatively the correction can be applied by means of a phase-shifting device inserted in all feeders except the first. The phase shift required in the second feeder will be $\left(\frac{d}{v}-\frac{d\cos\theta}{c}\right)2\pi f$, where f is the frequency of the signal. Other feeders will require correspondingly larger phase-shifts. Where $\left(\frac{d}{v}-\frac{d\cos\theta}{c}\right)f$ is greater than 1, only the fractional portion need be corrected.

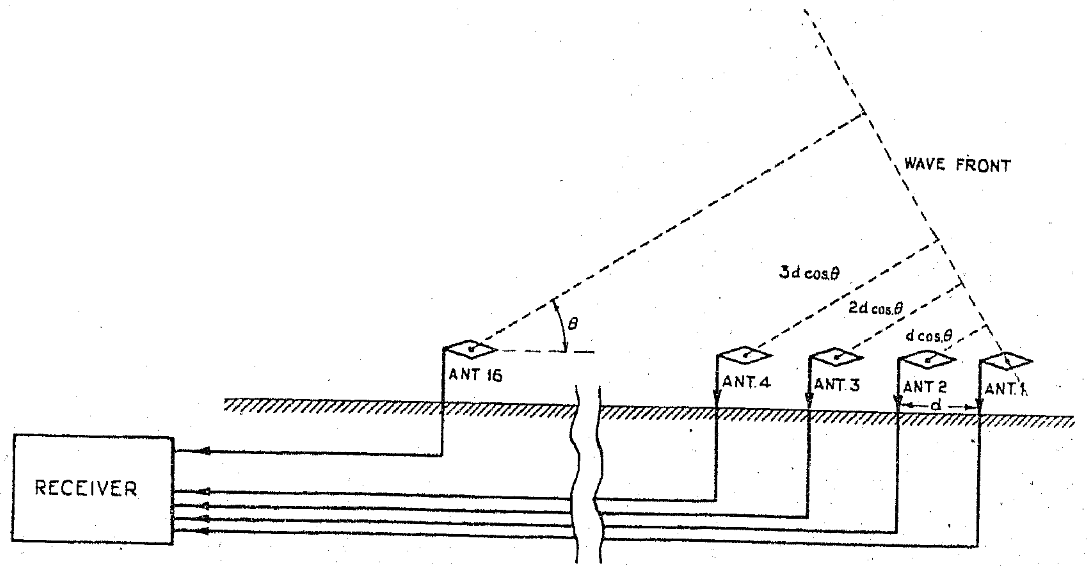


Fig. 20.—Principle of ray-diversity (M.U.S.A.) system.

As f enters into the expression the correction for a particular angle of incidence will not in this case hold for other frequencies. Both methods of correction would be equally effective. In practice, however, the correction is not inserted in the transmission lines but at a point after the first demodulator, so that the correcting devices operate at a constant intermediate frequency. As a result it is more convenient to use a phase-changer scheme, because of the facility of adjustment of such devices.

It is not essential to apply the phase correction to the signals; it is equally effective to arrange for the appropriate phase-change to be present in the beating oscillator supplies to the demodulators associated with the respective antennae and feeders. In the British receiver this method is adopted and the phase-changes are accomplished in rather a novel way which will be described later.

The vertical polar diagram of an array is given by the product of the response of the unit antenna and the array factor for corresponding wave angles. The unit antenna in the present case is a horizontal rhombic.

Such an antenna has a high gain and relatively constant output impedance over a wide range of operating frequencies. By suitable choice of the spacing of the unit antennae it can be arranged that the first major lobe of the polar diagram is caused to move over the range of downcoming wave angles normally met with in practice by a variation of the unit phase-shift of from + 180° to — 180°. The discrimination of the system is high for waves of differing downcoming wave angles which arrive along the great-circle path, but is relatively low for waves of the same downcoming angle which arrive "off course." Fortunately, the waves arrive "on course" for a large proportion of the time and it becomes possible to discriminate between waves of differing downcoming angles to a degree which is adequate in practice. It is possible with a single antenna system to provide more than one set of phase-shifters, so that the antenna system may be phased for optimum reception of more than one ray. These rays will in general correspond to signals which have travelled paths of different lengths. In order that full advantage may be taken of these multiple signals it can be arranged that the audio-frequency signals corresponding to the paths of shorter length are subject to suitable time delays in the receiver (by the use of suitable time-delay networks), so that they may be combined without distortion and with some improvement in the signal/noise ratio of the final output.

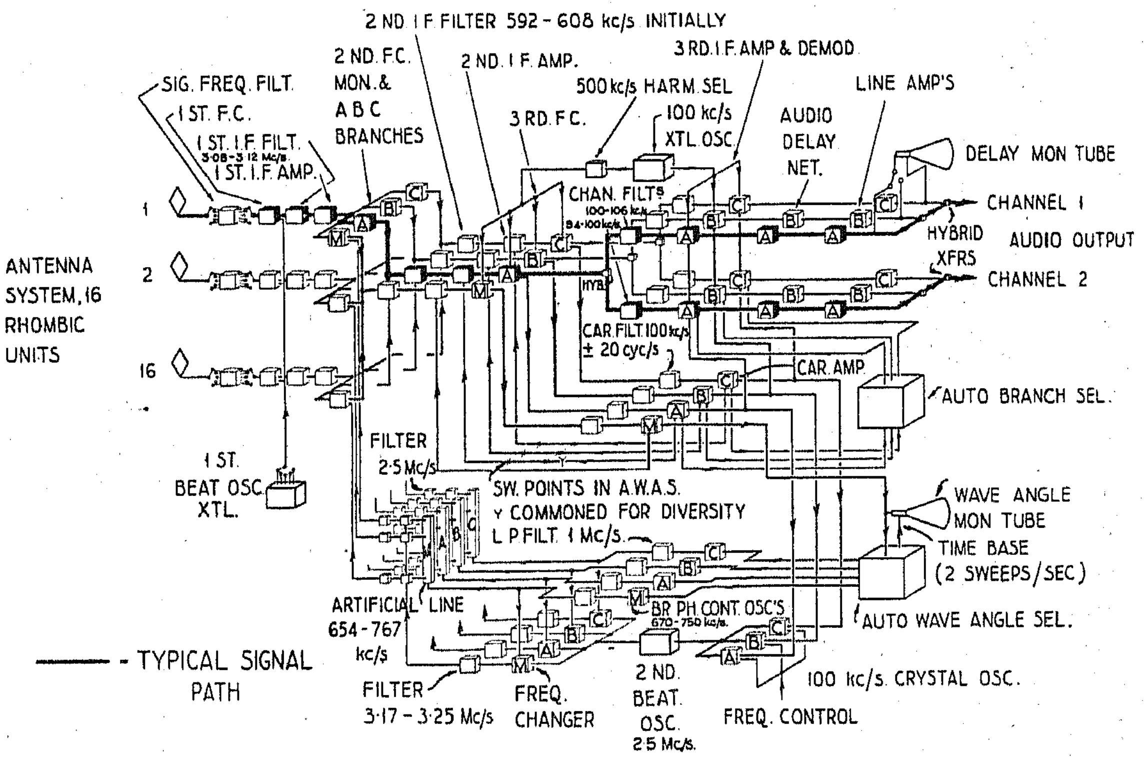


Fig. 21.—Block schematic of British ray-diversity receiver.

The signal/noise ratio advantage of the ray diversity system compared with the unit antenna depends in practice on the polar distribution of the radio noise or static which obtains in a given case. If, however, we assume that the static is negligible and that the major source of noise is the thermal-agitation voltage in the first tuned circuit of the receiver, a 16-element system should present a signal/noise gain of 16 times in power, owing to the combination of the 16 equal signal voltages in phase and the combination of the 16 sets of noise voltages in random phase. That is, the signal increases in power 256 times while the noise increases only 16 times. The improvement in signal/noise ratio is thus 10 $\log_{10}16$, or 12 db. This improvement, added to the improvement due to signal-sideband working, gives a total improvement of from 21 to 24 db. This is based on the assumption that only one branch of the receiver is contributing to the output. Three traffic branches are being fitted to the receiver, and when all three are adjusted to accept three rays arriving at three different angles, then, on the assumption that the three rays are of equal strength, there will be an additional improvement of 10 log 3 or 5 db. This condition will not obtain generally, as the three rays will vary in strength and the output from one branch will usually predominate at a particular time. Nevertheless, the presence of the three branches of the diversity system will reduce the number of fades in a given time, and will thus effect an improvement equivalent to a gain of this order. Thus the total improvement to be expected by a system of this kind compared with a double-sideband transmitter and single-unit antenna connected to the receiver should be from 26 to 29 db.

The antenna system comprises 16 rhombic antennae, the spacing between centres being 656 ft.

Each unit rhombic antenna is 60 ft. high, the side is 315 ft., and the included angle between the sides is 140°. The impedance of the antenna varies from approximately 850 ohms at 4 Mc./sec. to approximately 625 ohms at 22 Mc./sec. and is balanced to earth. The impedance is matched to the unbalanced coaxial copper-tube transmission line of impedance 70 ohms by a transformer suitable for operation over the range 4–22 Mc./sec. The transmission line consists of a $\frac{5}{8}$ in. diameter internal conductor inside a 2 in. diameter external conductor, and will be filled with dry air under pressure to retard the ingress of moisture. The loss on the longest line is expected not to exceed 6 db. at 20 Mc./sec. The lines are buried in the earth to minimize changes in length due to temperature variations and so to avoid the necessity for expansion joints. A schematic diagram of the British ray-diversity receiver is shown in Fig. 21. Three intermediate frequencies and three frequency-change steps are used. There is no signal-frequency amplification, but adequate protection against the image channel is obtained by the use of 3·1 Mc./sec. as the first intermediate frequency, together with a signal-frequency filter. The other intermediate frequencies are 600 and 100 kc./sec.; the design of this part of the receiver follows that of the single-sideband receiver already described. The receiver is provided with three traffic branches and a monitoring branch so that up to three waves of differing downcoming angles may be received separately and then combined. The purpose of the monitoring branch is to provide visual indication of how many rays are present and their relative strength so that the branch phase controls may be set accordingly either manually or automatically. Initially the receiver is equipped for two speech channels. The first and second intermediate-frequency amplifiers are designed for band-widths of 50 kc./sec. so as to make provision for possible multi-channel working.

Each transmission line may feed up to 6 receivers in parallel: when the working frequencies are sufficiently separated no loss of signal/noise ratio occurs. Each receiver is equipped with 5 sets of 16 pre-tuned input circuits, the appropriate set of circuits (each of which consists of two tuned circuits capacitively coupled) is selected and connected to the signal grids of the first frequency-changers by means of ganged switches.

Precautions are taken to maintain equality of phase-shift through the 16 signal and first intermediate-frequency circuits up to the combining point and means are provided to check and adjust this equality. The first tuned circuits are also adjusted to match the 70 ohms impedance of the transmission line to prevent reflection.

The first frequency-changers consist of two hexode valves in which the signal grids are fed in phase while the oscillator grids are fed in antiphase. This arrangement minimizes cross-talk between the pairs of frequency-changers via the common beating oscillator feed.

The first beating oscillator is crystal-controlled and uses low-temperature-coefficient quartz plates in thermostatically controlled ovens. The frequency stability of this oscillator is about ± 3 parts in 10^7. Spare oscillators are provided with an automatic change-over so that they may be put into service in the event of failure of the working oscillator.

A single stage of amplification at 3·1 Mc./sec. is provided, and the inductively coupled tuned circuits used constitute the first intermediate-frequency filter.

The second frequency-changer consists of 4 hexode valves with their signal grids connected in parallel. One of these valves is for the monitor branch and the remaining three for the signal branches. The oscillator grid on each of these frequency-changers is fed with 2·5 Mc./sec. from the appropriate branch phase-changer equipment, and the anodes of the 16 valves belonging to a given branch are connected in parallel. The phase-changer arrangement is shown in Fig. 22. The amount of phase-change produced is under the control of the oscillator O_1 (670 to 750 kc./sec.). This oscillator feeds, via the low-pass filter F1 (1 Mc./sec.), an artificial line L. This line consists of 32 confluent band-pass filter sections of the constant-K type terminated in an M-derived section. Each line unit consists of two filter sections each yielding + 90° to − 90° phase shift for a frequency variation of 670 to 750 kc./sec. The line is tapped at intervals of one line unit to feed a frequency-changer valve FC2. The phase shift between line taps is constant along the line, since the line is terminated in such a manner as to avoid reflection at the termination. The frequency-changers FC2 are also supplied with a frequency in the range 3·17–3·25 Mc./sec. derived from the oscillator O_2 (2·5 Mc./sec.) by modulating it with O_1 (670 to 750 kc./sec.) and selecting the upper sideband with the filter F2 (3·17 to 3·25 Mc./sec.). The frequency-changers FC2 now yield a beat frequency of 2·5 Mc./sec., but each output differs in phase from its neighbours by $\pm\, \phi$, where ϕ can be varied from − 180° to + 180° by varying the frequency of O_1 from 670 to 750 kc./sec.

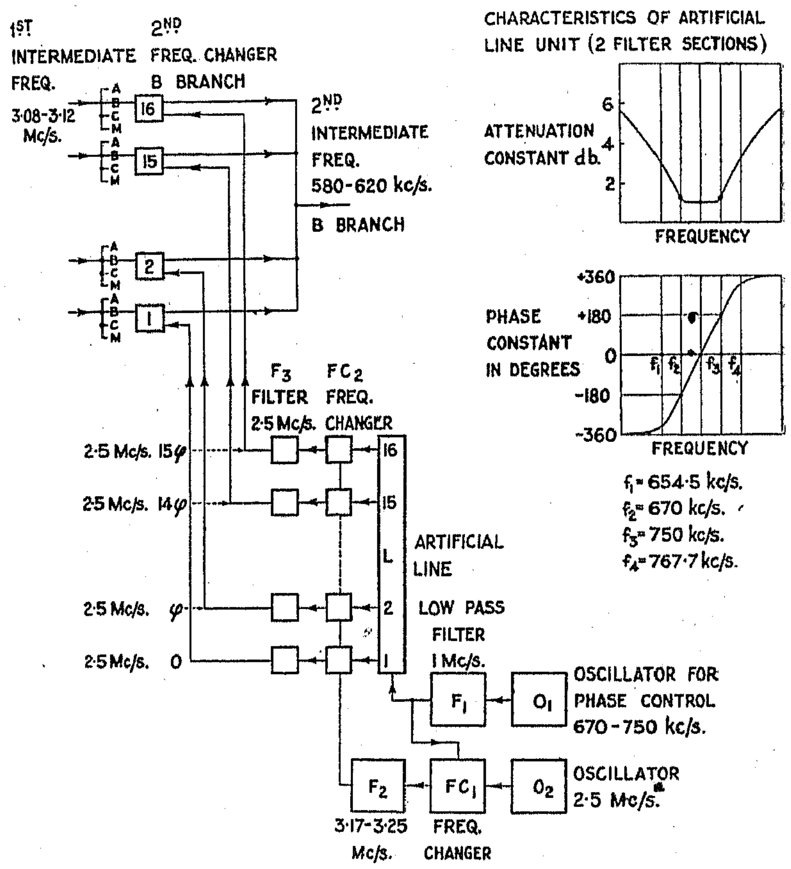


Fig. 22.—Principle of phase-changer.

The phase-control oscillators O_1 are arranged to be controlled in frequency both manually by a variable condenser and electrically by means of a direct voltage applied to a control valve. The advantages of this latter form of phase control lies in its freedom from mechanically variable elements (which is particularly important in the monitor branch), the ease with which it can be adapted to remote control, and its suitability for use in conjunction with a scheme for the automatic selection of the most suitable angles for reception by the traffic branches.*

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* It is interesting to note that the above system of phase correction can be used in the case where the receiver is placed at a point along the antenna system instead of at the end. Separate artificial lines, etc., are necessary to deal with space and line delays, however, in order that the difference between these phase shifts may be taken in the case of the forward aerials and the sum taken in the case of the rearward aerials.

The monitor branch of the receiver is arranged to sweep over the whole range of unit phase-shift (− 180° to + 180°) at a frequency of about 2 cycles per sec. This is achieved by applying a saw-tooth wave to the control valve of the phase-control oscillator of the monitor branch. This wave is also applied to the X plates of the monitor branch cathode-ray tube. The pattern observed on the fluorescent screen of this tube is a guide to the best setting of the branch phase-shifters. The low rate of sweep—2 cycles per sec.—is determined by the band-width of the carrier filter (40 cycles in this receiver). The monitor cathode-ray tube has therefore to be provided with a fluorescent screen having a slow decay time.

The frequency-control system of the receiver is identical in principle with that used in the single-sideband receiver already described. The direct control voltages from the three branch frequency-control units feed into a combining circuit to operate on a control valve associated with the second beating oscillator (2·5 Mc./sec.) of the receiver. The latter oscillator constitutes the only tuning control of the receiver and is variable in frequency over a range of about 5 kc./sec. only.

The automatic gain-control system, as in the single-sideband receiver, is of the delayed type operating from the pilot carrier. The control voltage is applied to two stages in the second intermediate-frequency amplifier. Provision is made for accurately tracking the variation of gain with control voltage in the three signal branch second intermediate-frequency amplifiers. This is necessary since normally the three branches operate with a common automatic gain control so that the signal of highest level contributes most to the audio output of the receiver.

The system of automatic angle selection favoured for adoption is one in which the branch phase-control oscillators are set automatically to the frequencies corresponding to the angle of the strongest incoming rays. If less than three waves of suitable level are present the selector will disconnect the unphased branches so that they do not contribute noise to the receiver output. When a wave ceases to appear above a certain level the branch which was phased for that ray is released and made available for phasing for any other ray which may appear or be present. Provision is also made for automatic branch selection whereby the branch carrying the strongest signal (as determined by the level of carrier in that branch) supplies the receiver output to the exclusion of the other two branches. This scheme is an alternative to combination with delay correction. The signal/noise advantage of combination with delay correction is slight unless the three branches yield signals of very nearly equal signal/noise ratios.

For delay correction audio delay up to 2·97 millisec. is provided in 9 steps of 300 microsec. together with 9 steps of 30 microsec. The delay networks are brought into circuit by the operation of relays; the relays are at present brought into action by a manually operated switch, but automatic correction may be fitted later.

By grading the contribution of each antenna to the combined output it is possible to reduce the size of the minor lobes of the polar diagram of the antenna system compared with the major lobe. This advantage is obtained at the expense of array gain, however. The increased discrimination offered by the scheme may be of advantage when the incoming bunch of rays consists of two or more components of slightly different down-coming angles but of different path lengths. Tapering in this receiver can be effected by adjustment of the gains of the 16 first intermediate amplifier stages by grid-bias control; grading may thus be introduced at will by operating a single switch.

The initial equipment at Cooling will consist of two receivers, each suitable for two speech channels. The equipment is mounted on standard 19-in. racks and for the two receivers consists of 88 bays. The total length of the receivers will therefore be about 110 ft. with an average height of about 8 ft. and the number of valves in use will be 1 079 for the two receivers. This seems a lot of equipment, but when it is realized that these receivers will give an improvement of about 1 000 over a simple receiver the complication becomes worth while.

It is of course obvious that any given improvement in a radio circuit can be obtained by increasing the power radiated by the transmitter or by increasing, within limits, the directivity of the transmitting or receiving aerials, and the decision as to where the improvement is to be obtained usually depends on the relative costs. In other words, one has to decide where a given number of decibels improvement can be obtained most cheaply.

For example, an improvement of 3 db. could be obtained by doubling the power of the transmitter, involving a cost of, say, £10 000. It might be possible, however, to get this 3 db. gain by doubling the size of the receiving antenna at a cost of, say, £1 000. Radio engineers have realized that for true economy of plant on a fixed radio service the cost of the receiver should approximate to that of the transmitter. Hitherto it has usually been cheaper to obtain improvements at the receiving end, as the total cost of the receiving equipment was generally much less than the cost of the transmitter. Now, however, the cost of the receiver has reached the same order as that of the transmitter, and if further transmission improvements become necessary in the future it seems probable that they will have to be obtained at the transmitting end.

In conclusion I should like to express my thanks to Mr. H. G. Beer and other colleagues in the Radio Laboratories for the great assistance I have received in the preparation of information for this address.

I must also acknowledge my indebtedness to the British Broadcasting Corporation for the data relating to the performance of the common-wave broadcasting transmitters.

A SENSE-FINDING DEVICE FOR USE WITH SPACED-AERIAL DIRECTION-FINDERS*

By R. A. FEREDAY, Ph.D.

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SUMMARY

A simple method is described for the rapid determination at a receiver of the sense of the direction of arrival of radiation from any transmitting station. A radio bearing of the station is taken in the usual manner with a four-aerial Adcock direction-finding system, and a second observation of minimum received signal is made after certain modifications to the electrical connections between the aerials have been effected by switching. The two observations are sufficient to determine without the usual ambiguity of 180° the bearing of the transmitting station at the receiver. The method is particularly suitable for use on high frequencies and with the visual type of receiver incorporating a cathode-ray tube.

(1) INTRODUCTION

The figure-of-eight polar diagram of direction-finders of the loop or spaced-aerial types leads to the usual ambiguity of 180° in the determination of the bearing of a transmitting station at the receiver. By the addition of a vertical aerial to the system the receiver polar diagram can be made to be of the form of a cardioid, in which case the bearing of any station can be obtained without any ambiguity. The cardioid receiver polar diagram, however, is obtained only for critical adjustment of both the relative phases and amplitudes of the two voltages impressed across the receiver input terminals from the directive and non-directive aerials. The degree to which this adjustment is possible with the usual type of direction-finder, modified for sense determination, is not sufficient for practical use of the receiver over a wide frequency range, especially on the shorter wavelengths. In particular, it is difficult to obtain any sense determination with the cathode-ray-tube type of receiver. An arrangement[†] has been described for determining the sense of the bearing of a transmitting station with such a receiver, but it involves considerable complexity in addition to being subject to difficulty in securing the required adjustment of the e.m.f. injected from the vertical aerial.

The method described below for the sense determination of a bearing involves only slight modification to any existing four-aerial Adcock system, and the procedure is extremely simple. After a bearing has been obtained in the normal manner, the electrical connections between the aerials are altered by means of a switch and a second observation is made. As is shown below, this second measurement is sufficient to determine the "sense" of the original bearing.

(2) SIMPLE SYSTEM APPLICABLE TO LONG WAVES

Consider a four-aerial Adcock system and suppose that radiation is incident on this array in a direction making the angle θ with the meridian. The phase-difference between the voltages induced in the north (N) and south (S) aerials is

$$\frac{2\pi d}{\lambda}\cos\theta$$

in which d is the distance between the aerials and λ the wavelength of the incident radiation. As these voltages are combined at the receiver in opposition, the voltage applied to the N-S field coil of the goniometer is

$$2E\sin\left(\frac{\pi d}{\lambda}\cos\theta\right) \quad . \quad . \quad . \quad . \quad (1)$$

in which E is the voltage due to either aerial. Similarly, the voltage in the E–W goniometer field coil is

$$2E\sin\left(\frac{\pi d}{\lambda}\sin\theta\right) \quad . \quad . \quad . \quad . \quad (2)$$

In measuring the bearing of a station the goniometer search-coil is rotated until the resultant of the two e.m.f.'s induced in it by the field coils is zero. This condition occurs when the search coil makes the angle ϕ with the N–S field coil, so that

$$\tan\phi = \frac{\sin\left(\frac{\pi d}{\lambda}\cos\theta\right)}{\sin\left(\frac{\pi d}{\lambda}\sin\theta\right)} \quad . \quad . \quad . \quad (3)$$

For aerial spacings small compared with the wavelength, equation (3) reduces to

$$\tan\phi = \cot\theta \quad . \quad . \quad . \quad . \quad . \quad (4)$$

the solution of which is

$$\phi = \theta + \pi/2 \quad . \quad . \quad . \quad . \quad . \quad (5a)$$

and

$$\phi = \theta + 3\pi/2 \quad . \quad . \quad . \quad . \quad . \quad (5b)$$

Equations (5*a*) and (5*b*) show the usual ambiguity of 180° in the location of a transmitting station by means of

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[*] Official communication from the National Physical Laboratory. Reprinted from *Journal I.E.E.*, 1939, vol. 84, p. 96.

[†] "The Cathode Ray Tube in Radio Research," p. 182 (H.M. Stationery Office).

any standard type of radio direction-finder. This ambiguity can be overcome, however, by making a second observation with one of the goniometer field coils connected to a single vertical aerial instead of to, say, the E–W Adcock pair. With this arrangement the e.m.f. induced by the N–S Adcock aerials in the goniometer search-coil, when the latter makes an angle ψ with the N–S field coil, is proportional to

$$\sin\left(\frac{\pi d}{\lambda}\cos\theta\right)\cos\psi$$

The e.m.f. induced in the search-coil by the single aerial connected to the normal E–W goniometer field-coil is proportional to $\sin\psi$. In order that these e.m.f.'s may be compared by the goniometer, it is necessary to include a phase-changing device in one circuit to bring them into phase. The resultant e.m.f. E in the search-coil is given, therefore, by

$$E = a\sin\left(\frac{\pi d}{\lambda}\cos\theta\right)\cos\psi + b\sin\psi \quad . \quad . \quad (6)$$

in which a and b are constants depending on the construction of any particular installation.

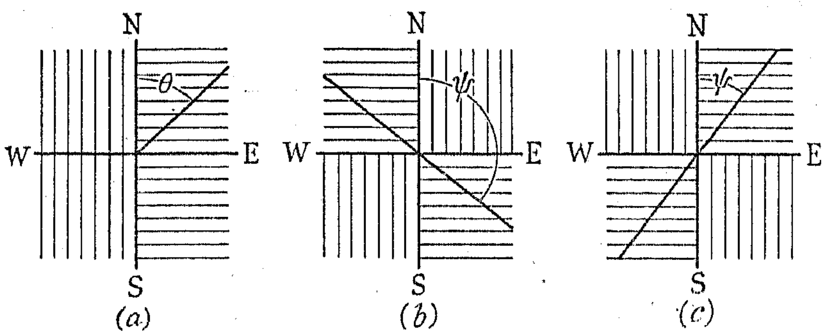

Fig. 1.—Relation between bearing θ of station and observed value of ψ for minimum received signal with combination of North and South Adcock aerials with non-directional aerial.

(b) a and b (eqn. 6) of same sign.
(c) a and b (eqn. 6) of opposite sign.

The phase-difference between the e.m.f.'s induced by the incident radiation in the Adcock aerial pair and the single vertical aerial is approximately $\frac{1}{2}\pi$. In the case of the aerials which are normally short compared with the wavelength, their impedance is mainly reactive, with the result that the current in them leads by $\frac{1}{2}\pi$ the e.m.f. induced in them. The impedance of the central aerial is also mainly reactive, but the aerial current may be made to have approximately the same phase as the e.m.f. by the insertion of a large resistance in series with the aerial. With this arrangement the output voltages of the N–S Adcock-aerial pair and the central aerial have approximately the same phase and can be applied to the two goniometer field-coils. The insertion of the resistance in series with the central aerial has the additional advantage that the attenuation introduced in this way makes the currents in the two goniometer field-coils of comparable magnitude.

It is shown in the Appendix that for the angles θ given in Fig. 1(*a*) which the direction of a station makes with the meridian at the receiver, the observed values of ψ determined from equation (6) for a signal minimum are given in Figs. 1(*b*) and 1(*c*) when the combination of the N–S Adcock aerials and the central aerial with added resistance is used. Figs. 1(*b*) and 1(*c*) correspond to the two possible conditions in which the constants a and b in equation (6) are respectively of the same, or of opposite, sign. The relative signs of these two factors for any particular installation are determined most simply by making sense observations on a local transmitter. If the E–W Adcock aerials and the vertical aerial were used, the relation between the bearing θ of a station and ψ the goniometer reading for minimum signal would be given by Figs. 2(*a*), 2(*b*), and 2(*c*). Whether Fig. 2(*b*) or Fig. 2(*c*) applied to the particular installation used would again have to be determined by observations on a local transmitter.

Suppose the station under observation lies in the N–E quadrant with respect to the receiver, and that observations with the local transmitter showed that when the E–W Adcock receiving aerials were replaced by a vertical aerial θ and ψ were related according to Figs. 1(*a*) and 1(*b*). A measurement with the complete Adcock system will show that the station lies at a certain angle to the meridian but in either the N–E or S–W quadrants. When the E–W Adcock aerials are replaced by the vertical aerial, however, the minimum received field condition is obtained when the goniometer search-coil is orientated so as to give a reading in the N–W or S–E quadrants. It will be seen from Figs. 1(*a*) and 1(*b*) that, for this condition to apply, the observed station must lie to the east of the meridian at the receiver. The two observations of minimum signal with the complete Adcock system and one Adcock pair with central aerial are sufficient, therefore, to determine without ambiguity the direction of arrival of the incident radiation.

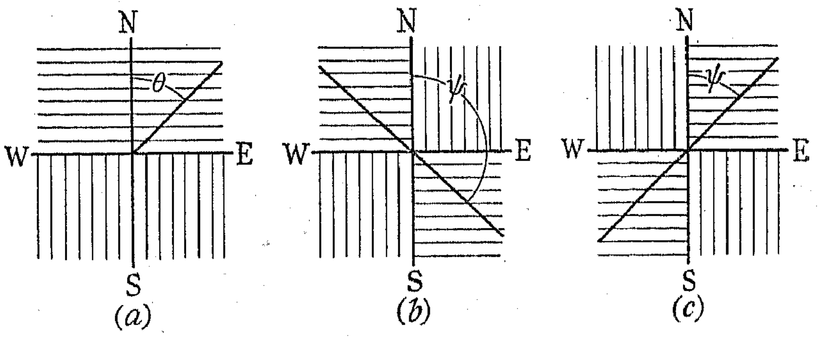

Fig. 2.—Relation between bearing θ of station and observed value ψ for minimum received signal with combination of East and West Adcock aerials with non-directional aerial.

It will be noted from Fig. 1 that if the station under observation lies due north or south of the receiver no sense resolution is possible. Similarly, for the conditions applying to Fig. 2, no sense resolution can be made in this case for radiation incident in the E–W direction. By adopting a system in which either Adcock-aerial pair may be used in conjunction with the vertical aerial for sense observation, these two directions of " no sense " resolution may be avoided.

(3) SYSTEM SUITABLE FOR USE ON SHORT WAVELENGTHS

The system described above is not suitable for use on short wavelengths unless the phase-delays introduced by the long leads from the aerials to the receiver are matched by an equivalent phase-delay introduced in the central aerial circuit. The complication can be avoided, however, if the non-directional aerial output is obtained from the second Adcock-aerial pair instead of from the central aerial. In order to make this second Adcock-aerial pair approximately non-directional, the two component aerial outputs must be combined additively instead of in opposition. This arrangement simulates closely that used on longer wavelengths with the single non-directional aerial, but all phase-delays introduced between the aerials and the receiver remain of comparable magnitude in the new arrangement. High resistances in series with the non-directional unit are still required, in order that the currents in the two goniometer field-coils may be approximately in phase.

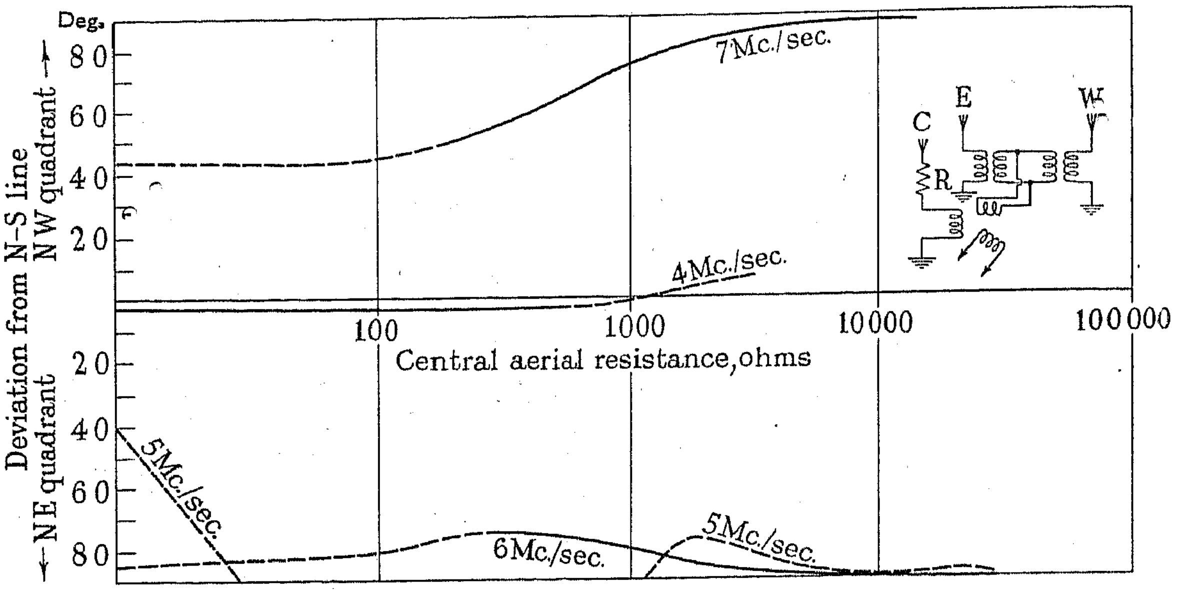

Fig. 3

The analysis of the case in which both Adcock-aerial pairs are used for sense observations is very similar to that for one Adcock-aerial pair and the single vertical aerial. The results given in Figs. 1 and 2 apply to the new system, the particular condition corresponding to any installation being again determined with the use of a local transmitter. This system also suffers from the fact that there is a direction of "no sense" resolution with either Adcock pair used as the non-directional unit, but, by arranging that either pair of Adcock aerials is used for this purpose, sense resolution is possible for all directions of arrival of the incident radiation.

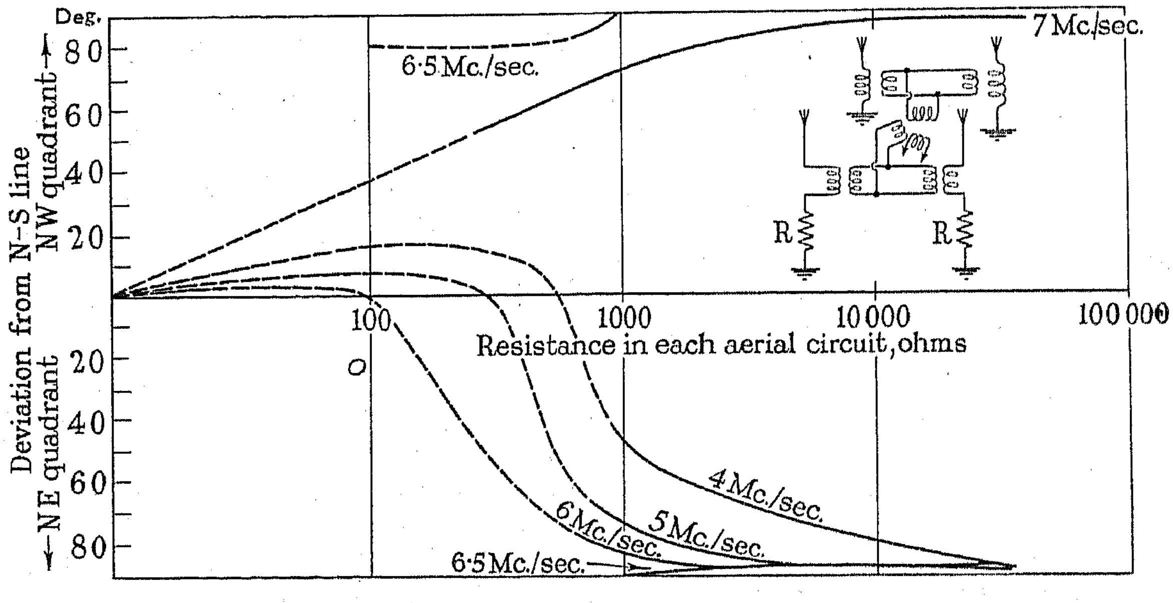

Fig. 4

(4) EXPERIMENTAL INVESTIGATION

There is a direction with both the sense-finding arrangements described above, for which no sense resolution is possible unless either pair of the Adcock aerials can be used as the directive element. It is desirable, in practice, that the relative amplitudes of the currents in the two goniometer field-coils should be such that this sector for no sense resolution is as narrow as possible. In testing various arrangements, measurements were made with a local transmitter set up at an angle of 90° from the centre of the "no sense" resolution sector of an Adcock-aerial pair and central aerial system. In the earlier experiments, the N–S aerials of a four-aerial Adcock system rather similar to that described by Barfield and Ross,* were replaced for sense-finding by a vertical aerial having characteristics as similar as possible to those of the individual aerials of the system. The curves in Fig. 3 show the results obtained with this arrangement at three frequencies in the neighbourhood of aerial resonance (6·6 Mc./sec.) when resistances of different values were inserted (as shown inset) in series with the single aerial. The dotted portions of the curves correspond to observations requiring swings greater than

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* *Journal I.E.E.*, 1937, vol. 81, p. 682; and *Proceedings of the Wireless Section*, 1938, vol. 13, p. 39.

± 10° for the determination of the minimum received signal condition, and therefore to conditions unsuitable for practical purposes. With resistances of between 500 and 2 000 ohms good sense-finding measurements were possible even for radiation almost in the direction of " no-sense " resolution. The difference of approximately 180° in the sense readings at 6 and 7 Mc./sec. was due to the resonance of the aerial system occurring between these frequencies. At 5 Mc./sec., resistance values exceeding 50 000 ohms were required for proper phase adjustment, but the attenuation introduced in this way was such that the output from the central aerial was not sufficient for sense indication. The correct phase relationship at 4 Mc./sec., on the other hand, required such a small resistance that the output from the central aerial swamped that of the E–W Adcock pair.

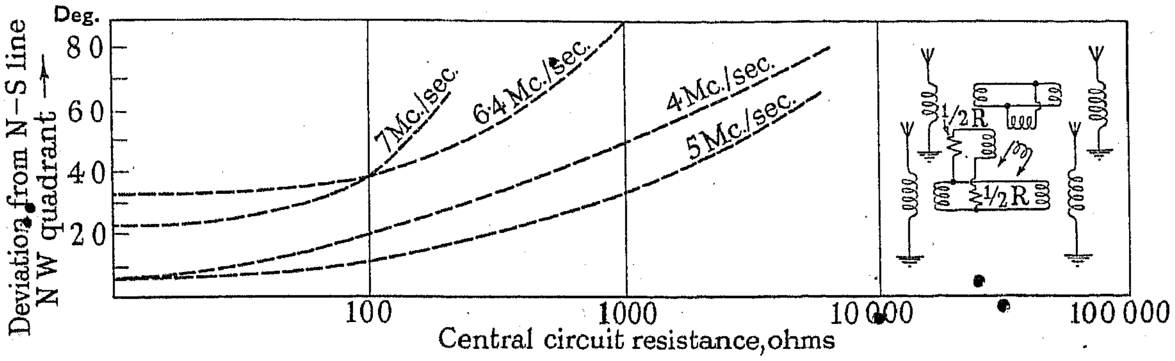

Fig. 5

Table

Frequency, Mc./sec.	Station	Location	Normal		Sense A		Sense B	
			Bearing, deg.	Swing, deg.	Reading, deg. >90 = E <90 = W	Swing, deg.	Reading, deg. >180 = S <180 = N	Swing, deg.
4·0	G5PG	Ditton Park	352	2	85	10	179	2
4·6	RUK	Stalinabad	85	50	95	10	167	30
4·8	RVS	Mourmansk	35	30	98	25	173	15
5·0	OEY	Deutsch-Altenburg	102	25	95	12	193	20
5·3	WEU	New Brunswick, N.J.	290	20	84	15	165	30
5·6	OXZ	Lyngby	57	20	95	10	168	20
6·7	OZS	Skamlebäk	50	20	102	20	160	20
6·7	IEO	Rome	135	20	100	20	190	20
6·7	OLH	Prague	95	10	100	20	240	50
7·8	WIF	Brentwood, N.Y.	290	80	80	40	160	60
7·9	FTY	S. Assise	143	15	110	40	190	20
8·1	JNO	Nagoya	35	20	110	40	165	15
8·4	OXZ	Lyngby	No bearing	Flat	100	40	170	40
8·4	WSL	Amagansett	285	50	75	20	167	30
8·5	DAN	Norddeich	63	30	107	20	156	20
8·6	ORM	Ruysselede	99	20	110	10	225	20
9·0	HBC	Berne	130	20	105	10	192	20
9·1	IBF	Rome	131	20	103	10	192	20
9·1	HAT4	Budapest	107	15	102	15	202	15
9·2	GIV	Oxford	304	10	77	5	167	5
9·3	LCB	Oslo	40	10	107	10	167	10
9·3	JUJ	Tokyo	30	60	105	50	170	40
9·6	RAL	Moscow	65	30	104	20	160	30
9·6	DJA	Zeesen	82	10	102	10	255	10
9·8	EAM2	Arranjuez	185	10	40	60	191	10
9·8	DFE	Nauen	75	20	105	20	165	4
9·8	LSI	Monte Grande	220	20	75	20	190	20
10·0	OLG	Prague	93	10	104	10	(See text)	
10·0	IES	Rome	135	20	97	15	185	50
10·0	KUW	Manila, Philippine Is.	50	60	105	90	170	60
10·0	FTL	S. Assise	140	20	105	20	195	30

The improvement obtained when the central aerial was replaced by a reversed Adcock-aerial pair can be seen from the curves in Fig. 4, which show that at any frequency there was a relatively wide range of resistance values for which the necessary degree of phase and amplitude matching was satisfied. This is particularly evident at frequencies near the resonant frequency of the aerial system. The practical frequency range of this Adcock system was limited by aerial resonance at about 4 Mc./sec. and by secondary-circuit resonance at 10 Mc./sec. Between these two frequencies the sense-finding device functioned satisfactorily. It will be seen from the curves in Fig. 5 that, with the system shown inset in that figure, unsatisfactory results were obtained when the phase-adjusting resistances were inserted in the circuit coupling the two aerials forming the non-directional unit to the goniometer.

Measurements made on ground stations with a permanent installation using the sense-finding circuit shown in Fig. 4 are given in the Table. The observed bearing of each station made with the normal Adcock system is given in the fourth column, and the corresponding sense observations with the two possible aerial connections in the sixth and eighth columns. The interpretation of these sense observations is possible from the key given above each column. The swing of the goniometer search-coil required for any observation is shown in the column immediately succeeding that giving the observation. It will be noted that sense determination was possible for all stations with either pair of aerials as the non-directive element. In the case of one station (OXZ) the required swing when taking a bearing was so great that the bearing could not be determined. The two sense observations, however, were more definite and were sufficient to determine the quadrant in which the bearing of the station lay. The station OLG (bearing normally 93°) showed variations in bearing from angles less than 90° to values greater than 90°. The sense indication for discrimination between N and S showed corresponding swings.

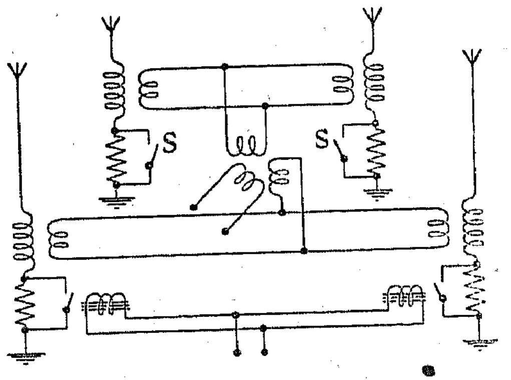

Fig. 6

A sense-finding system similar to that described above and shown diagrammatically in Fig. 6 has been in use for some time with both visual and aural types of receiver. In the installation with visual recording, the time taken to obtain a sense indication on a normal ambiguous bearing is negligible, so that the system is at no disadvantage compared with one in which an unambiguous bearing is given directly. It was found experimentally with the permanent installation employing aural reception that an aerial resistance of 5 000 ohms was satisfactory. A carbon resistance of this value was connected to each aerial near its base and was normally short-circuited by a mercury switch, the operating relay of which was located at some distance from it and was operated by a mechanical link of insulating material. In this way the leads carrying the relay current were kept well away from the aerials and feeders, and so were prevented from forming a low-impedance circuit between the aerials at the signal frequency. The switch controlling the relay was so arranged that when the resistances were inserted in the aerials the connections of the latter to the goniometer were also reversed, so that the change from a normal Adcock direction-finding system to the modified sense-finding arrangement was made in one operation. By using either pair of Adcock aerials as the non-directional element, sense resolution was possible for radiation incident in any direction. In order to simplify the interpretation of results, small replicas of Fig. 3 or Fig. 4 were illuminated automatically according to the aerial arrangement in use.

(5) ACKNOWLEDGMENTS

The work described above formed part of the programme of the Radio Research Board, and this paper is published by permission of the Department of Scientific and Industrial Research. The author desires to acknowledge his indebtedness to Dr. J. S. McPetrie for help in the method of presentation of the paper, and to Mr. R. E. Burgess for assistance in the experimental work.

APPENDIX

$$E = a \sin\left(\frac{\pi d}{\lambda}\cos\theta\right)\cos\psi + b\sin\psi \quad . \quad . \quad (6)$$

In order to find the minimum value of $|E|$ with respect to ψ it is convenient to determine the minimum value of E^2.

$$E^2 = a^2 \sin^2\left(\frac{\pi d}{\lambda}\cos\theta\right)\cos^2\psi + b^2\sin^2\psi$$
$$+ ab \sin\left(\frac{\pi d}{\lambda}\cos\theta\right)\sin 2\psi \quad . \quad (7)$$

The minimum value of E^2 must occur when the third term in equation (7) is negative. Four conditions are possible:—

(i) *a and b same sign, cos θ positive.*

For these conditions $\sin 2\psi$ is negative, that is

2ψ lies between 180° and 360°, or 540° and 720°,

or ψ[*] lies between 90° and 180°, or 270° and 360°.

(ii) *a and b same sign, cos θ negative.*

For these conditions $\sin 2\psi$ must be positive.

Therefore 2ψ lies between 0° and 180°, or 360° and 540°,

or ψ lies between 0° and 90°, or 180° and 270°.

(iii) *a and b opposite sign, cos θ positive.*

This gives the same values of ψ as Case (ii).

(iv) *a and b opposite sign, cos θ negative.*

This gives the same values of ψ as Case (i).

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[*] ψ is measured from the N-S line.

THE DEPENDENCE ON FREQUENCY OF THE TEMPERATURE-COEFFICIENT OF INDUCTANCE OF COILS*

By H. A. THOMAS, D.Sc., Member.

(*Paper first received 6th April, and in final form 9th June,* 1938.)

SUMMARY

Evidence is given that the temperature-coefficient of inductance of coils is dependent on frequency, owing to the change with temperature of the current distribution over the conductor cross-section. The effect is of importance only over a limited range of section for any particular frequency band.

The theory of the effect is examined for circular-section conductors. It is shown that in all self-supporting helical coils suitable for short-wave work, where the conductor radius is greater than 0·1 cm., the effect of change of current distribution with temperature-change is such that no appreciable increase of temperature-coefficient of inductance occurs. For coils wound with very fine wire the temperature-coefficient of inductance is not affected appreciably by change of current distribution. The effect of temperature on the current distribution and consequently on the coefficient of inductance is appreciable only when the conductor radius lies between the limits 0·001 and 0·2 cm. In such cases the coefficient has a component due to this effect which may be quite high over an appreciable frequency band. This condition occurs in practice with deposited or sprayed-on conductors. The temperature-coefficient of inductance of coils having a conductor section within the defined range reaches a maximum value at a particular frequency and is less at frequencies above and below this value.

Experimental verification is given of the conclusion arrived at in the theoretical discussion, together with an explanation of the behaviour of certain coils having ceramic formers. The conclusions arrived at from a study of such coils are applied to the design of coils suitable for use at high radio frequencies, and it is shown that the best type of construction from the point of view of electrical stability is one in which the radial thickness of the conductor is small compared with the radius of the turn while the axial spacing is large.

CONTENTS

(1) Introduction.
(2) Discussion of Observations of the Temperature-coefficient of Inductance of a Ceramic-former Coil.
(3) The effect of Frequency Variation on the Temperature-coefficient of Inductance of Straight Wires of Circular Cross-section.
(4) Experimental Verification of the Dependence on Frequency of the Temperature-coefficient of Inductance of Coils.
  (*a*) Experiments with a coil having a grooved silica former.
  (*b*) Experiments with a coil having a skeleton former.
  (*c*) Conclusions from experiments on fine-wire coils.

CONTENTS—*continued*

(5) Application of the Theory to the Determination of the Temperature-coefficient of Inductance of Coils.
  (*a*) General.
  (*b*) Coils having an appreciable radial depth of section.
  (*c*) Coils with flat-wise strip conductors.
(6) Acknowledgments.

(1) INTRODUCTION

In a previous paper† observed values of the temperature-coefficient of inductance of a number of coils have been tabulated‡ and an explanation has been given of the properties of such coils in terms of the mechanical deformation which occurs with variation of temperature. Nearly all the coils considered in this work had conductors of appreciable area of cross-section. More recently the behaviour of coils with conductors of very small cross-section has been studied and it has been found that the change of inductance with temperature is considerably greater than the theoretical value corresponding to the mechanical changes which occur. It has also been observed that the temperature-coefficient of inductance is a function of frequency, a property which appears to be peculiar to coils having certain shapes and sizes of conductor section.

One object of this paper is to present the data obtained on such inductance coils and to show that the observed behaviour is consistent with a theory involving the distribution of the radio-frequency current in the conductor section. A further object is to show what types of coil are liable to exhibit this phenomenon to a marked degree and what types of construction should be avoided if a high stability of inductance with respect to temperature is desired.

Although evidence of a variation of the temperature coefficient of inductance with frequency has been obtained from tests made on a number of coils wound with copper wire of small circular section, the most notable case of this phenomenon was obtained with a coil consisting of a copper conductor deposited on a ceramic former. The variation with frequency of the temperature-coefficient of inductance of this coil is plotted in Fig. 1 (curve marked "observed coefficient"). It will be noticed that the coefficient at a frequency of 10 Mc./sec. is about five times as great as the value at low frequencies. The properties of this coil were found to be so unusual that it was considered advisable to make a very careful analysis of the various factors which might conceivably be responsible for this anomalous behaviour.

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* Official communication from the National Physical Laboratory. Reprinted from *Journal I.E.E.*, 1939, vol. 84, p. 101.

† H. A. Thomas: "The Stability of Inductance Coils for Radio Frequencies," *Journal I.E.E.*, 1935, vol. 77, p. 702; and *Proceedings of the Wireless Section*, 1936, vol. 11, p. 44.

‡ *Loc. cit.*, Table 1.

(2) DISCUSSION OF OBSERVATIONS OF THE TEMPERATURE-COEFFICIENT OF INDUCTANCE OF A CERAMIC-FORMER COIL

The mechanical dimensions of this particular coil were as follows:—

Diameter .. .. .. 6 cm.
Number of turns 18
Ratio: Length/diameter .. 2 (approx.)
Axial spacing between turns 0·4 cm.

The electrical constants were:—

Inductance .. .. = 11·4 μH
Self-capacitance .. .. = 2·2 $\mu\mu$F
Resistance .. .. = 0·35 ohm
Natural frequency .. = 31·7 Mc./sec.
Permittivity of ceramic former .. .. .. = 6·5
Temperature-coefficient of permittivity of former material .. .. (σ) = $+ 160 \times 10^{-6}$ per deg. C.
Expansion coefficient of former material .. (α) = $+ 7 \cdot 8 \times 10^{-6}$ per deg. C.

The section of the deposited conductor is shown in Fig. 1. It is impossible to measure directly the thickness of this deposit but, if it is assumed to be uniform and to have the normal conductivity of copper, the thickness can be calculated from the measured d.c. resistance. The value obtained on these assumptions is 0·0275 mm. and can be taken as an approximation to the actual value; the thickness is probably not constant over the whole conductor length.

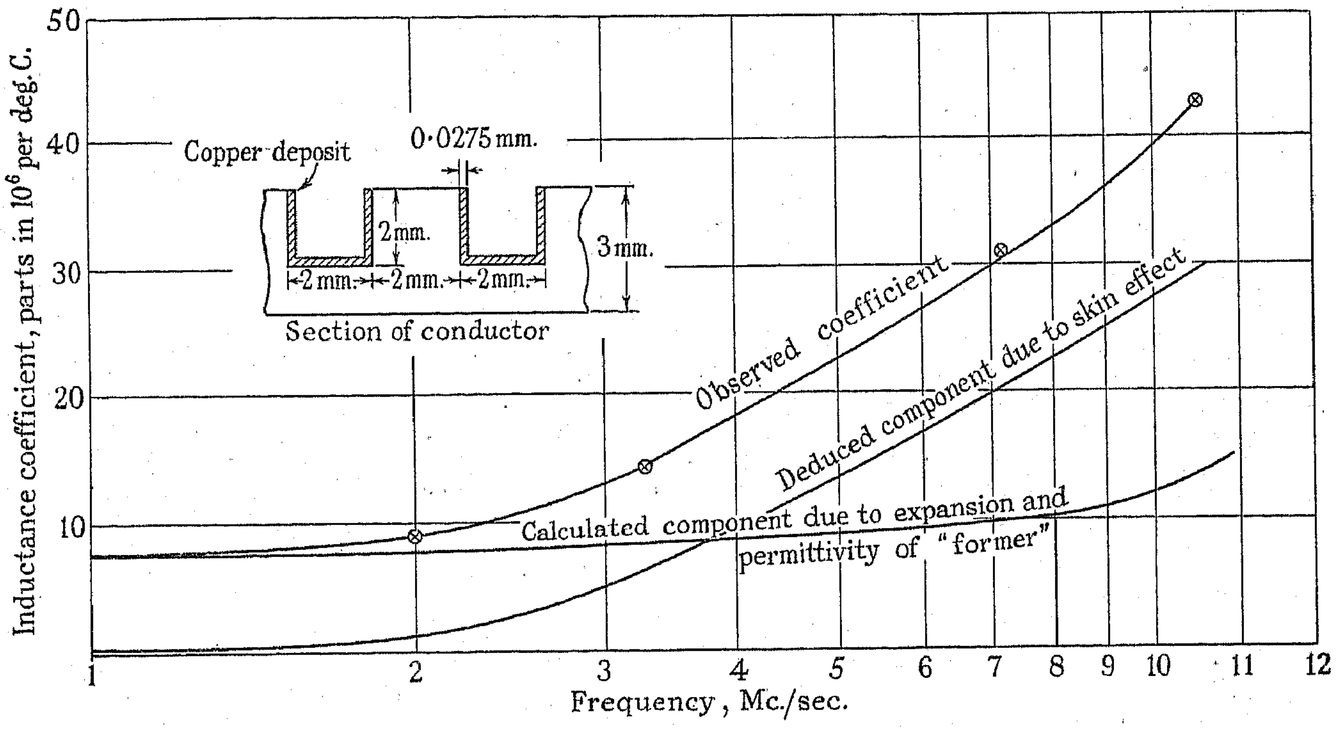

Fig. 1.—Analysis of components of inductance coefficient of ceramic-former coil.

(a) Effects attributable to Change of Self-capacitance with Temperature

Howe's empirical formula for self-capacitance gives $C = 0 \cdot 64 r$ $\mu\mu$F for an air-spaced coil in which the length is twice the diameter and r is the radius of the coil in centimetres. For the coil now being considered the theoretical value of the self-capacitance, for an air dielectric, is 1·92 $\mu\mu$F. Measurements of the natural frequency of this coil, together with audio-frequency bridge measurements, have shown that the actual self-capacitance is 2·2 $\mu\mu$F; the difference between this and the theoretical value is presumably attributable to the permittivity of the "former."

Table 1

Self-Capacitance Components of Ceramic-Former Coil

Values of self-capacitance components	Micro-micro-farads	Percentage of total capacitance
Self-capacitance to earth ..	1·56	71
Mutual capacitance of turns	0·64	29
Total self-capacitance ..	2·20	100

Now it can be assumed for the purpose of an approximate explanation that the self-capacitance has two components, one due to the electric flux within the solid dielectric and the other due to the flux from the turns to earth through the air dielectric. For the purpose of computing the first component it can be assumed that the electric flux between two adjacent turns for the particular conductor section shown in Fig. 1 is confined to the solid dielectric, and that the electric field density is uniform. Furthermore, if it is assumed that the current at all points in the coil is the same, then it can readily be shown that the value of the capacitance component due to the solid dielectric is 0·64 $\mu\mu$F. This means that the remaining 1·56 $\mu\mu$F is due to the surrounding electric field to earth. The actual and percentage values of the two components of the self-capacitance are given in Table 1. If the ceramic former were removed, the mutual capacitance of the turns would be reduced from

$0 \cdot 64\ \mu\mu$F to $0 \cdot 094\ \mu\mu$F and the total capacitance would be $1 \cdot 66\ \mu\mu$F. The presence of the "former" therefore increases the self-capacitance by only 33 %.

It is interesting to compare this result with certain measurements given by Jackson* in which it is shown that the increase of capacitance due to the presence of a paxolin former is only 23 %. The permittivities of paxolin and of the ceramic former used in these tests are about 4 and $6 \cdot 5$ respectively. Jackson's results suggest, therefore, that the increase of self-capacitance due to the ceramic former should be $23 \times 6 \cdot 5/4$ or 37 %. The agreement between this experimental result and the previously calculated effect of the solid dielectric is noteworthy. It is quite clear from these measurements that the self-capacitance is only affected to a slight degree by the presence and nature of the " former " material.

The temperature-coefficient of frequency of an oscillation circuit in which the tuning capacitance is independent of temperature is given by the following expression:—

$$\frac{\Delta f}{f} = \frac{1}{2}\left[\alpha + \sigma\left(\frac{C_s}{C + C_s}\right)\right] \quad . \quad . \quad . \quad (1)$$

in which α = expansion coefficient of " former " ($7 \cdot 8 \times 10^{-6}$ per deg. C. in this case),

σ = temperature-coefficient of permittivity of "former" ($+ 160 \times 10^{-6}$ per deg. C. in this case),

C_s = capacitance due to permittivity of " former,"

C = sum of all other capacitances not affected by temperature.

In the particular case of the ceramic-former coil $C_s = 0 \cdot 64\ \mu\mu$F and C is an inverse function of frequency, its minimum value of $1 \cdot 56\ \mu\mu$F occurring at the natural frequency of the coil. The temperature-coefficient of inductance due to expansion and change of permittivity of the " former " is plotted against frequency in Fig. 1, together with the inductance coefficient of the coil. It will be seen that there is a much greater rise in the temperature-coefficient of inductance than can apparently be explained by the mechanical or electrical changes in the " former." This conclusion was confirmed by measurements of the expansion coefficient, permittivity, and temperature coefficient of permittivity of the material of which the " former " was made.

The fact that the observed discrepancy between the measured and calculated values of the temperature-coefficient of inductance increases rapidly with frequency suggests a change of inductance with temperature-rise which is not due to alterations of shape.

(b) Effects attributable to Variation of Current Distribution with Temperature

It is well known that the increase of resistance of a conductor with temperature produces a re-distribution of the current flowing in the section. This will change the effective inductance, but this variation of current distribution with temperature has hitherto been considered to be of negligible importance. It is true that Groszkowski* has observed appreciable effects arising from this cause in the case of certain coils of rather unusual construction, but if the part of the temperature-coefficient of inductance which is due to change of conductor resistance with temperature is calculated for any normally-wound short-wave coil it will be found that it is exceedingly small. For example, the results of measurement on a former-less coil of large conductor section are given in Table 2. This particular coil consisted of 8 turns of copper wire of circular cross-section wound helically, the radius of the wire being $0 \cdot 32$ cm., the diameter of the coil $8 \cdot 4$ cm., and the turn spacing $0 \cdot 84$ cm.

Table 2

EXPERIMENTAL RESULTS ON FORMER-LESS COIL

Frequency	Temperature-coefficient of inductance
kc./sec.	parts in 10^6
3 297	+ 7
11 518	+ 8
13 350	+ 12
18 062	+ 5

The results show that no increase in the coefficient of the nature and magnitude under consideration occurred over a large frequency range. It appeared, therefore, at this stage of the work that appreciable increase of temperature-coefficient of inductance with frequency was peculiar to coils of very small conductor sections.

An examination of the dependence of the temperature coefficient on frequency and cross-section has been made, from which it has been found that effects due to current redistribution with resistance-change are by no means unimportant in certain cases, although previous conclusions to the contrary were quite correct for the particular cases then considered. The nature of the effect is such that its influence on the temperature-coefficient of inductance may be very considerable when the conductor section becomes comparable with that of a deposited metallic film. The unique electrical feature of deposited coils is not the presence of the dielectric material but the fact that the section of the conductor lies within a critical range where changes of resistance due to temperature give rise to appreciable temperature-coefficients of inductance.

(3) THE EFFECT OF FREQUENCY VARIATION ON THE TEMPERATURE-COEFFICIENT OF INDUCTANCE OF STRAIGHT WIRES OF CIRCULAR CROSS-SECTION

The self-inductance of a conductor depends appreciably on the field within its cross-section; any deviation of the distribution of the current from uniformity always gives rise in practice to a decrease of inductance. The value of this decrease depends on the frequency of the current, on the size and shape of the cross-section of the conductor, and on the conductivity and permeability of the conductor. This decrease of inductance is always accompanied by an increase in resistance of the conductor. The inductance approaches a limiting value with increasing frequency, whereas the resistance increases indefinitely. Unfortunately, the rigorous solution of the problem at high frequencies for the various cases for which the inductance with steady currents may be calculated is in many instances very difficult, if not impossible. Some of the simpler cases, however, have received attention, with the result that the changes of inductance and resistance may be calculated with reasonable accuracy.

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* W. JACKSON: " The Self-Capacitance of Single-Layer Coils," *Philosophical Magazine*, 1935, vol. 19, p. 823 (see Table 3).

* J. GROSZKOWSKI: " The Temperature Coefficient of Inductance," *Proceedings of the Institute of Radio Engineers*, 1937, vol. 25, p. 448.

Formulae for calculating the change of inductance as a function of frequency for straight cylindrical wires, two parallel wires, and circular rings of circular section, have been given by Rosa and Grover.* For a straight cylindrical wire,

$$\frac{\Delta L}{L} = -\frac{\left(1 - \frac{4}{x}\cdot\frac{Z}{Y}\right)}{\left(4\log\frac{2l}{\rho}\right) - 3} \quad . \; . \; . \; . \quad (2)$$

in which ΔL = change of inductance at frequency f,
L = d.c. value of inductance,
l = length of conductor in cm.,
ρ = radius of conductor in cm.,
$x = 2\rho\sqrt{\left(\frac{\pi p\mu}{\sigma}\right)}$,
σ = specific resistance of conductor (1 722 e.m.u. at 20° C. for copper),
μ = permeability of conductor,
f = frequency = $p/(2\pi)$,
Z/Y = a function of x.

The functions Y and Z are given as

$$Y = (\text{ber}'\,x)^2 + (\text{bei}'\,x)^2$$

and $$Z = \text{ber}\,x\;\text{ber}'\,x + \text{bei}\,x\;\text{bei}'\,x$$

where ber x and bei x are functions introduced by Kelvin, being respectively the real and imaginary parts of the Bessel function of order zero, J_0, having for its argument $xj\sqrt{j}$, where x is a real quantity and $j = \sqrt{-1}$.

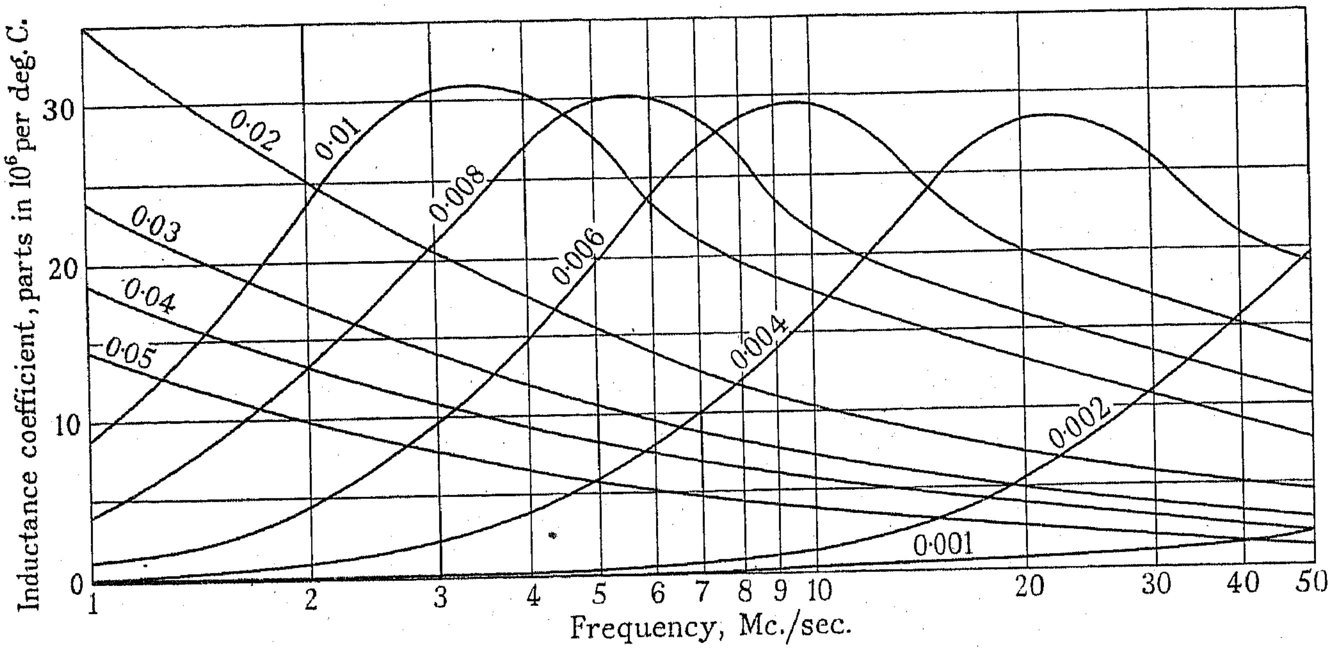

Fig. 2.—Dependence of inductance coefficient of straight copper wire on conductor radius and frequency.
l = 320 cm.

These functions are given by the series

$$\text{ber}\,x = 1 - \frac{x^4}{2^2 . 4^2} + \frac{x^8}{2^2 . 4^2 . 6^2 . 8^2} \cdots$$

$$\text{bei}\,x = \frac{x^2}{2^2} - \frac{x^6}{2^2 . 4^2 . 6^2} + \frac{x^{10}}{2^2 . 4^2 . 6^2 . 8^2 . 10^2} \cdots$$

and ber′ x and bei′ x are their differential coefficients with respect to x.

The values of Y and Z have been evaluated and are given in Table 22 of Rosa and Grover's paper.*

The limiting value of the change of inductance is

$$\left(\frac{\Delta L}{L}\right)_{x=\infty} = -\frac{1}{4\log(2l/\rho) - 3} \quad . \; . \; . \quad (3)$$

and since

$$L_{x=0} = 2l\left[\log\frac{2l}{\rho} - 1 + \frac{\mu}{4}\right]$$

$$= 2l\left[\log\frac{2l}{\rho} - \frac{3}{4}\right] \quad \text{for copper}$$

$$(\Delta L)_{x=\infty} = -\,l/2 \quad . \; . \; . \; . \; . \; . \; . \quad (4)$$

Thus the decrease of inductance (in centimetres) when the frequency is indefinitely increased is equal to half the length of wire (in centimetres) and is independent of the area of cross-section. The change of inductance is a function of the quantity:—

$$x = 2\rho\sqrt{\left(\frac{\pi p\mu}{\sigma}\right)} \quad . \; . \; . \; . \; . \; . \quad (5)$$

$$= 0\cdot2142\rho\sqrt{f} \quad \text{for copper at } 20° \text{ C.}$$

By using Table 22 in Rosa and Grover's paper to obtain the variation of the function $\left(\frac{4}{x}\cdot\frac{Z}{Y}\right)$ for small changes of x and then determining the temperature-change required to produce this same change of x over a band of frequencies, it is possible to obtain the component of the temperature-coefficient of inductance due to the re-distribution of current over the circular cross-section. The results of this analysis for wires of varying radius and a constant length of 320 cm. are shown in graphical form in Fig. 2, the radius in centimetres being stated for each curve. For shorter lengths, the temperature-coefficient of inductance is increased by the multipliers shown in Table 3, the form of the curve remaining unchanged in each case.

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* "Formulae and Tables for the Calculation of Mutual- and Self-Inductance," *Bulletin of the Bureau of Standards*, 1912, vol. 8, p. 1.

* *Loc. cit.*

Table 3

INDUCTANCE-COEFFICIENT MULTIPLIERS FOR VARIOUS LENGTHS OF WIRE

Length of conductor (cm.)	Radius of wire (cm.)									
	0·001	0·002	0·004	0·006	0·008	0·01	0·02	0·03	0·04	0·05
10	1·38	1·41	1·45	1·47	1·49	1·51	1·57	1·60	1·64	1·67
20	1·29	1·30	1·33	1·34	1·36	1·37	1·41	1·43	1·45	1·47
40	1·20	1·21	1·23	1·23	1·24	1·25	1·28	1·29	1·31	1·32
80	1·13	1·13	1·14	1·14	1·15	1·15	1·17	1·18	1·18	1·19
160	1·06	1·06	1·07	1·07	1·07	1·07	1·08	1·08	1·08	1·09
320	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00

Table 3 shows that values of the temperature-coefficient of inductance derived from Fig. 2 are modified only slightly by appreciable changes in the length of conductor. When applying the results of this analysis to all ordinary shapes and sizes of single-layer coils it will be found that the " proximity " effect is not usually very appreciable, except in cases where adjacent turns are nearly in contact; the " straight-wire skin-effect " components plotted in Fig. 2 are rarely increased by more than 20 %.

An examination of Fig. 2 shows that the temperature-coefficient of inductance due to change of resistance is quite large over a rather limited range of both conductor radius and frequency. A maximum value of this coefficient occurs at a definite frequency for each size of conductor, the value decreasing very slightly with decreasing radius. The frequency at which this practically constant coefficient is obtained decreases as the radius of the conductor is increased, with the result that over any particular frequency band there is some corresponding range of conductor size which gives appreciable values of the temperature-coefficient of inductance. The maximum values of the coefficient of inductance together with the frequencies at which they occur are given in Table 4 for circular-section conductors of various sizes.

These maximum values of the temperature-coefficient of inductance all occur when x equals 3·85, which means that the rate of change of inductance is a maximum for this particular value of x. The existence of such a maximum value can be anticipated on physical grounds. At low frequencies, with nearly uniform current distribution, the rate of change of inductance with resistance variation is small; at infinite frequency, with wholly peripheral current distribution, it is asymptotically zero. It is obvious, therefore, that it reaches a maximum at some intermediate frequency. With wires of large diameter, this particular distributional condition exists at a comparatively low frequency, and consequently at high radio frequencies the self-inductance is approaching its limiting upper value. With wires of small diameter, however, this particular distributional condition occurs at a very high frequency and consequently over the normal radio-frequency band the inductance does not change appreciably from its steady-current value.

Table 4

MAXIMUM VALUES OF TEMPERATURE-COEFFICIENT OF INDUCTANCE OF CIRCULAR-SECTION STRAIGHT COPPER WIRES

Radius of conductor (l = 320 cm.)	Maximum value of inductance coefficient	Frequency at which maximum value occurs
cm.	parts in 10^6	(Mc./sec.)
0·001	25·2	322
0·002	26·5	80·5
0·004	28·2	20·2
0·006	29·4	8·95
0·008	30·0	5·05
0·01	30·8	3·22
0·02	32·8	0·81
0·03	34·2	0·358
0·04	35·5	0·202
0·05	36·4	0·129
0·10	39·5	0·032

Referring to Fig. 2, it is seen that appreciable temperature-coefficients of inductance may occur within the radio-frequency range 1 to 50 Mc./sec. if the radius of the wire lies between 0·001 and 0·10 cm., corresponding approximately to 50 S.W.G. and 14 S.W.G. respectively.

(4) EXPERIMENTAL VERIFICATION OF THE DEPENDENCE ON FREQUENCY OF THE TEMPERATURE-COEFFICIENT OF INDUCTANCE OF COILS

(a) Experiments with a Coil on a Grooved-Silica Former

In view of the fact that within the frequency range 1 to 20 Mc./sec. the temperature-coefficient of inductance may be appreciable only for wires of small diameter, it is necessary in conducting experiments on such coils to ensure that the dimensions of the "former" shall be sensibly independent of temperature and that the method of winding shall be such as to give very precise location of the fine-wire conductor. For this purpose a silica tube was used to support the wire, the outer and inner radii of this tube being 6·7 and 5·6 cm. respectively; a spiral groove was cut on this tube with a pitch of 0·5 cm., and a coil of 8 turns was wound on to this former. The inductance of the coil so formed was about 5·4 μH.

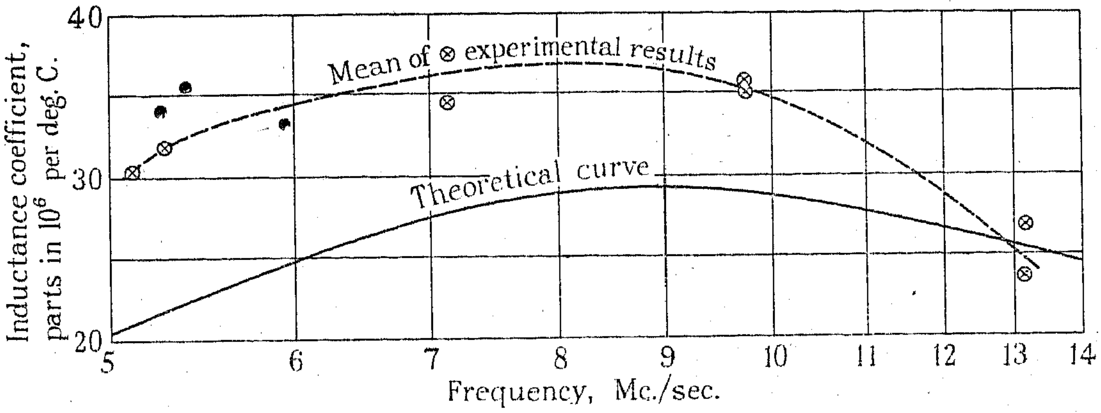

Fig. 3

Radius of conductor, 0·0061 cm. (No. 40 S.W.G.).

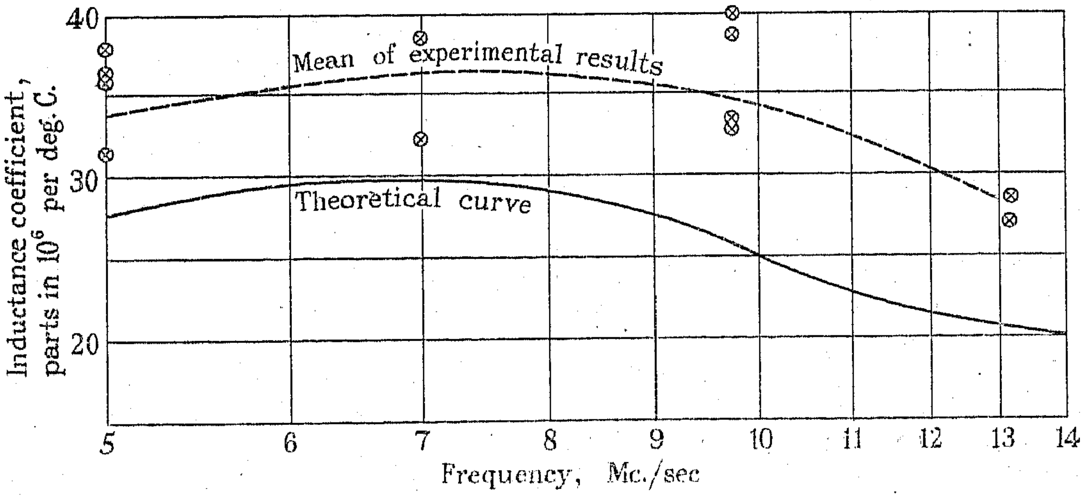

Fig. 4

Radius of conductor, 0·0076 cm. (No. 38 S.W.G.).

The temperature-coefficient of inductance was measured over a band of frequencies for three wire sizes, viz. No. 40 S.W.G. (0·0061 cm. radius), No. 38 S.W.G. (0·0076 cm. radius), and No. 36 S.W.G. (0·0096 cm. radius). In each case bare copper wire was used, wound under slight tension.

The experimental results obtained are plotted against frequency in Figs. 3, 4, and 5, for the above-mentioned three gauges. Although the accuracy of repeat observations at any particular frequency is not high, there appears to be definite evidence of a frequency effect. For instance, the form of the curve shown in Fig. 3 is essentially different from that shown in Fig. 5. The coefficients plotted are the total values due to expansion and skin effect. It has been shown previously* that the component of the temperature coefficient of inductance due to expansion alone for a coil of this type may be expected to be about half the temperature coefficient of expansion of the wire. Consequently in this case a positive temperature-coefficient of inductance of about 9 parts in 1 million can be attributed to the coil at frequencies well removed from the range where skin-effect phenomena are of significance. Subtracting this value of 9 parts in 1 million from the experimental results plotted in Figs. 3, 4, and 5, quite good agreement is obtained between the observed and the calculated coefficient due to variation of current distribution with temperature-change.

(b) Experiments with a Skeleton-Former Coil

In the previous case the conductor was in close contact with the former. It was considered advisable to repeat the measurements, using a coil in which the conductor was supported on a skeleton former. For this purpose a silica tube was used of the same dimensions as before, six thin glass plates were cemented to the outside, and grooves were cut in these plates to locate the wire. In this way a hexagonally-shaped winding of 8 turns was wound on a former of negligible expansion coefficient. The coil so formed had a circumscribed diameter of 8·6 cm. and a turn spacing of 0·5 cm.

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* H. A. Thomas: *Journal I.E.E.*, 1935, vol. 77, p. 708; and *Proceedings of the Wireless Section*, 1936, vol. 11, p. 44. (See Coil F in Table 1 of this paper.)

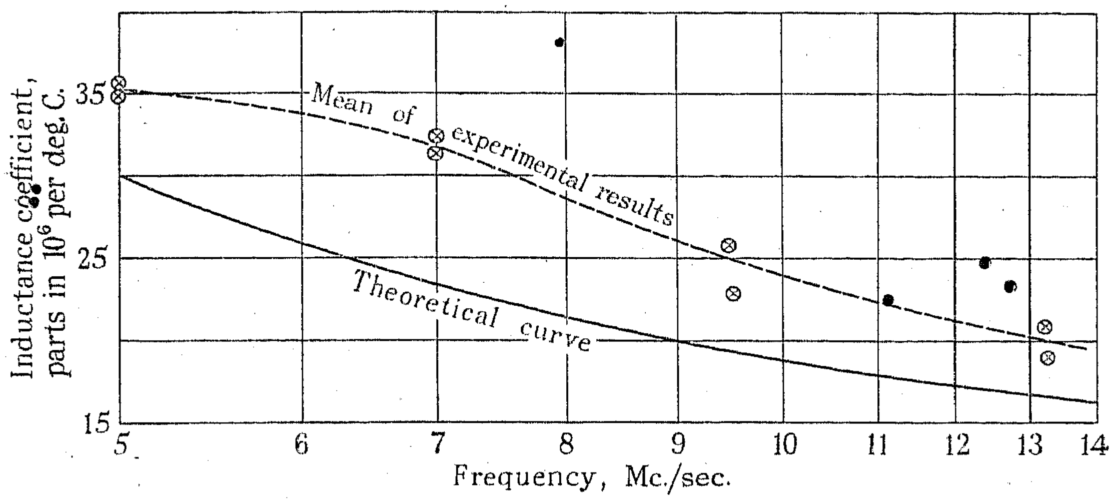

Fig. 5
Radius of conductor, 0·0096 cm. (No. 36 S.W.G.).

Using a winding of No. 34 S.W.G. (0·0117 cm. radius) copper wire, the temperature-coefficient of inductance was measured at a frequency of 4·1 Mc./sec., and was found to be + 97·5 parts in 1 million per deg. C. Several check measurements were made at the same frequency, and in all cases agreement to within 5 % was obtained. The wire was now removed from the former and rewound; the inductance coefficient was found to be + 5·4 parts in 1 million per deg. C.; a second rewind gave a value of + 17 parts in 1 million per deg. C.

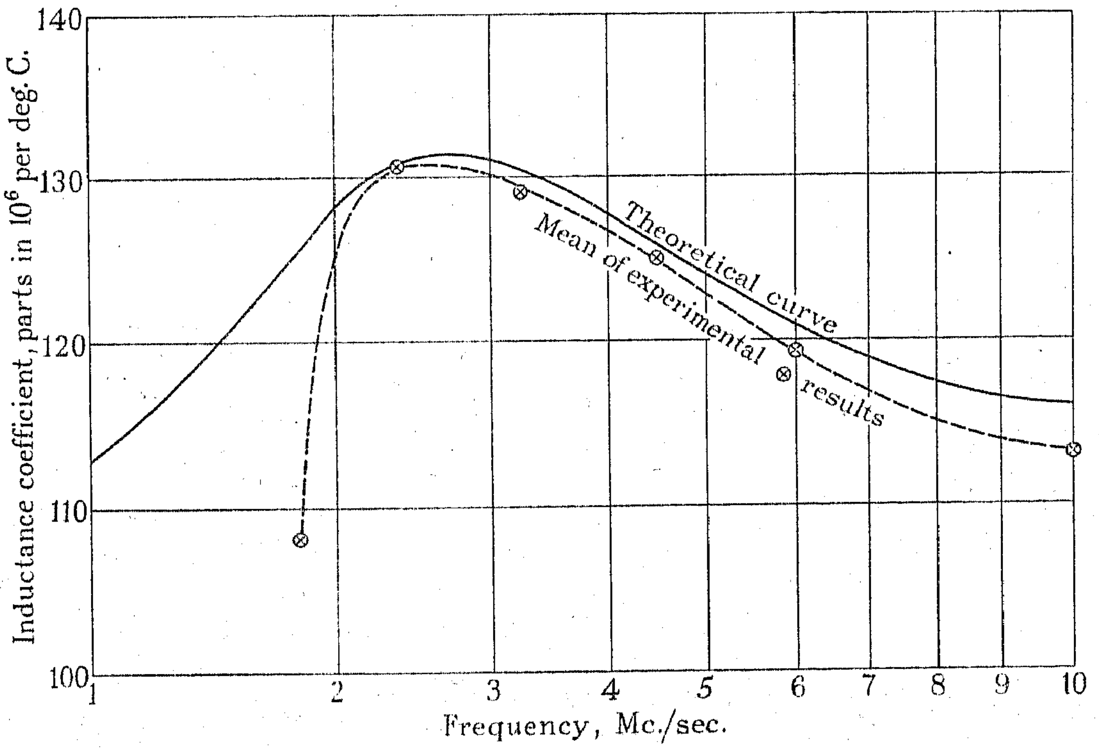

Fig. 6
Radius of conductor, 0·0117 cm. (No. 34 S.W.G.).

It is apparent from these results that the coefficient of a lightly-supported fine-wire coil may lie between wide limits, but for any particular winding very good agreement between successive results was always obtained and, furthermore, slight mechanical vibration did not affect the behaviour. It seemed probable that the various observed coefficients for the same wire and former could only be produced by a different set of winding stresses, which would in turn give rise to different forms of mechanical distortion on heating. If this were the case, variation of frequency should change the coefficient by the amount calculated for skin-effect alone.

With the object of demonstrating whether this took place the temperature-coefficient of inductance was measured at a number of frequencies over the band 1 to 10 Mc./sec. The results are shown in Fig. 6, from which it is seen that good agreement was obtained with theory. In this case—the third rewind—the coefficient attained a maximum value of 130 parts in 1 million per deg. C. The coil was now wound with No. 26 S.W.G. (0·0228 cm.

radius) copper wire and measurements were made over the same frequency range. The results plotted in Fig. 7 show that in this case no maximum value was obtained at a particular frequency. The agreement with the theoretical curve for this wire size is not so good as in the other cases, the curve showing only a slight rise in coefficient with fall of frequency.

(c) Conclusions from Experiments on Fine-Wire Coils

The experiments described above furnish evidence in support of the theory given in Section (3). In the case of a coil consisting of a fine wire tightly wound on a former which rigidly fixes its position at all points, the temperature-coefficient of inductance has two components. One component (i) is equal approximately to the mean value of the expansion coefficients of the metal and the former, and is equal approximately to the calculated coefficient of a straight wire of the same size due to current redistribution with change of resistance.

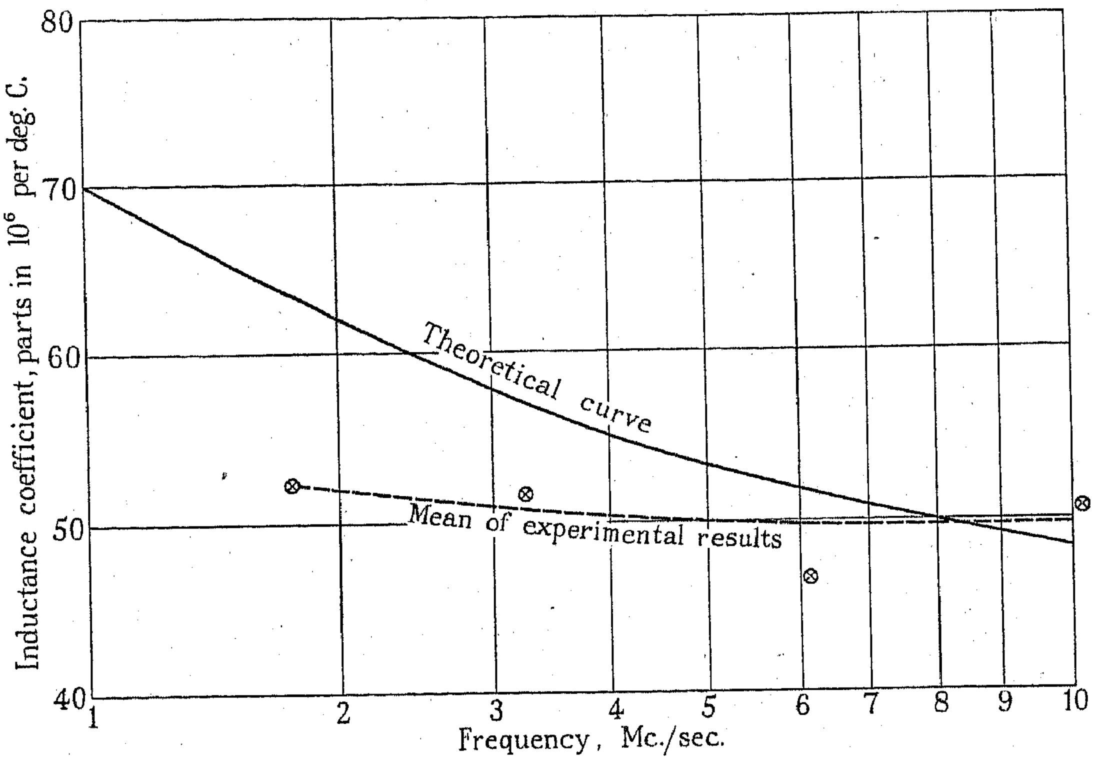

Fig. 7

Radius of conductor, 0·0228 cm. (No. 26 S.W.G.).

When the fine wire is not completely constrained by the former but is located only at a few points, the temperature coefficient is again made up of two components, (ii) being the same as before. Component (i) is, however, incalculable since it appears to be caused by the unknown stress distribution in the wire due to winding. It should be noted that in such a coil a large portion of the wire is stressed beyond the elastic limit, which condition is known to be a fruitful source of abnormal distortions. Furthermore, it is well known that a hexagonal coil cannot be wound with the conductor under considerable stress except in the case of very fine wires, and general observation of such skeleton-former coils when heated shows that the relative movement between turns is very large and quite indeterminate.

It is clear that whereas a coil fully supported on a good former has a low temperature-coefficient of inductance which is calculable, a partially-supported coil is definitely unsuitable if constancy of inductance and a low temperature-coefficient of inductance is desired.

(5) APPLICATION OF THE THEORY TO THE DETERMINATION OF THE TEMPERATURE-COEFFICIENT OF INDUCTANCE OF COILS

(a) General

The theory of the variation of inductance with frequency for straight wires of circular section is applicable to coils within fairly well-defined limits. The variation of inductance of a coil with frequency is due partly to the change of self-inductance of the circular turns and partly to the change of mutual inductance between turns. Reference to Table 23 of Rosa and Grover's paper* shows that if a straight-wire conductor is bent into the form of a circular ring the fractional change of inductance with frequency is increased from the straight-wire value by an amount which rarely exceeds 20 % for most practical shapes and is usually much less. The change of mutual inductance between turns depends upon the diameter of the wire and the spacing of the turns, and for closely-wound coils in which the mutual inductance forms an appreciable part of the total inductance it is found that the temperature-coefficient of inductance of the coil is about double the straight-wire value. For self-supporting coils in which the spacing between turns is appreciable the effect of the mutual inductance between turns is not so large.

In general, the values of the temperature-coefficient of inductance plotted in Fig. 2 can be considered to represent approximately the performance of most short-wave coils using circular-section conductors. These values are strictly valid for coils of small conductor cross-sectional area and large turn spacing; for closely-wound coils of large conductor cross-section, the temperature-coefficient of inductance may be as high as $2\frac{1}{2}$ times the values given, but such cases are unusual.

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* *Loc. cit.*

(b) Coils having an Appreciable Radial Depth of Section

In the case of the coil discussed in Section (2), exact computation of the current distribution at radio frequencies for the U-shaped section illustrated in Fig. 1 is impossible, but it can be seen in general terms that, as the frequency increases, the current density will increase at the inner surface of the strip base of the conductor and will diminish up the side walls. Consequently the shift of the mean current axis at infinite frequency will be greater than one-half the thickness of the deposit.

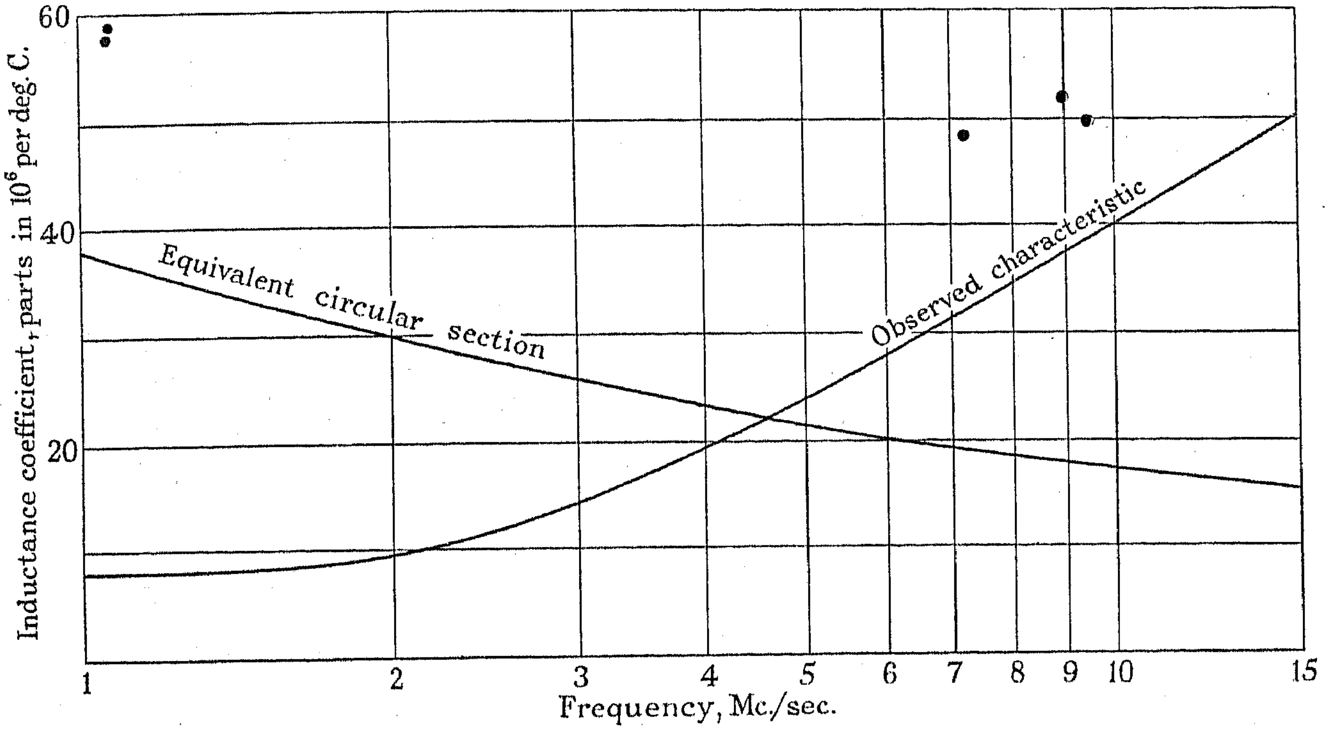

Fig. 8.—Characteristics of U-section coil.

The equivalent circular section to give the same d.c. resistance has a diameter of 0·46 mm., and the calculated temperature-coefficient of inductance of this equivalent section is shown in Fig. 8 together with the observed characteristic for the U-shaped section. The ratio of the effective radio-frequency resistance to the d.c. resistance (R_e/R_0) is also plotted for the same two cases in Fig. 9. It is seen that the use of the U-shaped section has reduced the effective resistance quite appreciably and has reduced the temperature-coefficient of inductance over a large frequency range. The rise in coefficient above a frequency of 3 Mc./sec. is due probably to the shift of the mean current axis; it should be noted, however, that the form of the variation of the temperature-coefficient of inductance with frequency differs from that of a circular-section conductor of the same area owing to the difference between the nature of the current redistribution with frequency-change.

If the depth of the conductor section in a plane perpendicular to the axis of the coil is an appreciable fraction of the coil radius, it is no longer justifiable to calculate the maximum change of inductance on the basis of subtracting the flux within the section from the flux within the coil, thus assuming at very high frequencies that the current is distributed uniformly within an infinitely thin layer bounding the conductor section. If it is assumed for a closer approximation of the actual current distribution at high frequencies that the current is concentrated on the inner edge of the conductor section, then the fractional change of inductance will be approximately equal to half the radial depth of section divided by the mean radius of the turn; in the case of the ceramic-former coil already referred to, this is 3·3 %. If, however, it is assumed that the current at high radio frequencies is concentrated within an infinitely thin layer uniformly bounding the U-shaped conductor section, the calculated change of inductance will be much less than 1 %.

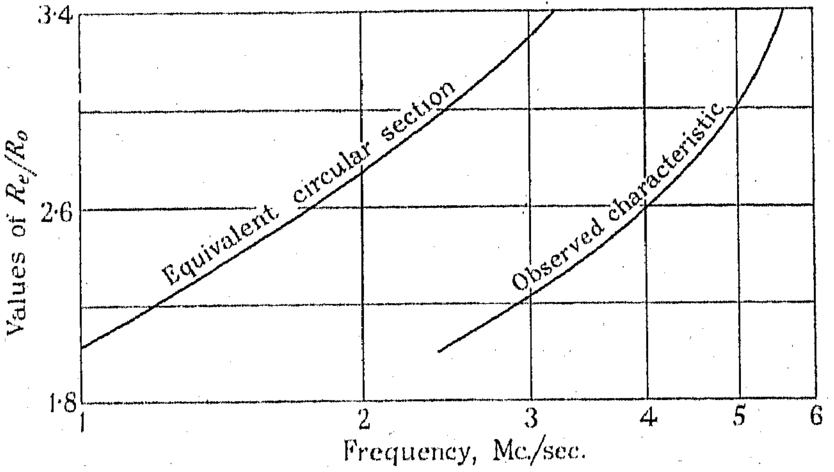

Fig. 9.—Characteristics of U-section coil.

With the object of obtaining further data on coils having a large radial depth of section, a coil was made of 12 turns of edge-wound copper strip 0·0315 cm. wide; the internal and external radii of the coil were 3·75 and 5·05 cm. respectively, and the turn spacing was 1 cm. The measured inductance at 500, 1 000, and 2 000 cycles per sec., was 7·04 μH and may be regarded as the low-frequency value. Over the range of radio frequencies 1·8 to 3·9 Mc./sec. the inductance was 6·58 μH; the self-capacitance was 2·81 μμF and the natural frequency of the coil was 37·01 Mc./sec. The reduction of inductance from low to high frequencies is therefore 6·6 %, whereas the ratio of half the depth of the section to the mean radius is 14·7 %; in this case the inductance change from low to high frequency is very nearly equal to half the ratio of the radial depth of the conductor to the mean turn radius.

Table 5

	Coil 1	Coil 2
Number of turns	29·5	34·5
Thickness of conductor	0·16 cm.	0·16 cm.
Axial turn spacing	0·16 cm.	0·16 cm.
Inner radius	18·7 cm.	18·7 cm.
Outer radius	22·5 cm.	21·3 cm.
Observed change of inductance	7·8 %	7·3 %
Ratio: $\frac{\frac{1}{2}(\text{Conductor width})}{\text{Mean radius}}$	9·2 %	6·5 %

Another somewhat similar case is given by Morecroft.[*] The inductance of two edge-wound ribbon coils was measured over the frequency range 0·043 to 150 kc./sec., the results obtained and details of dimensions being given in Table 5.

In these tests the change of inductance is also very nearly equal to the ratio of half the conductor width to the mean radius.

It is evident from the results of measurement that the change of inductance with frequency may be quite large in those cases where the radial depth of the conductor section is appreciable; this will apply to flat ribbon conductors wound edgewise, or to U-shaped sections. If this effect is to be made small the radial depth must be reduced. In the case of the ceramic-former coil described this means that the walls of the section should be removed, since strip wound flatwise should show little trace of this effect.

(c) Coils wound with flatwise strip conductors

In accordance with the previous conclusion, tests were made on two coils having flatwise strip conductors on a ceramic former. The details of the coils are given in Table 6.

Table 6

	Coil A	Coil B
Diameter	30 mm.	30 mm.
Number of turns	23	18
Ratio: $\frac{\text{Length}}{\text{Diameter}}$	2·5	1·8
Width of section	2 mm.	1·5 mm.
Radial depth of section	0·0076 mm.	0·035 mm.
Axial turn spacing	3 mm.	3 mm.
Inductance	6·3 μH	4·8 μH
Self-capacitance	1·6 μμF	1·4 μμF
Resistance	2·4 Ω	0·57 Ω
Natural frequency	52 Mc./sec.	59 Mc./sec.
Permittivity of ceramic former	6·5	6·5
Temperature coefficient of permittivity of former material	$+ 160 \times 10^{-6}$ per deg. C.	$+ 160 \times 10^{-6}$ per deg. C.
Expansion coefficient of former material.	$+ 7·8 \times 10^{-6}$ per deg. C.	$+ 7·8 \times 10^{-6}$ per deg. C.
Diameter of equivalent circular-section to give same d.c. resistance	0·15 mm.	0·26 mm.

The observed temperature-coefficient of inductance of

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[*] "Principles of Radio Communication," 2nd ed., p. 195.

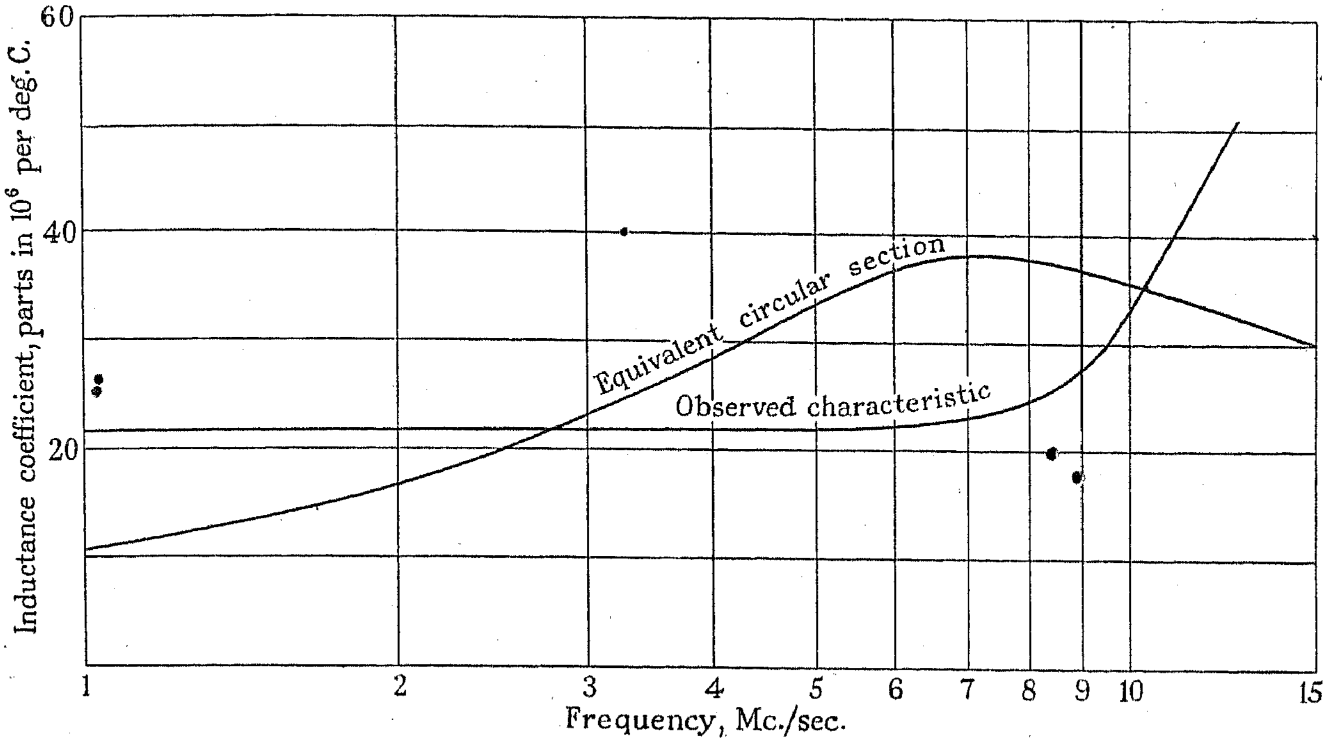

Fig. 10.—Characteristics of Coil A.

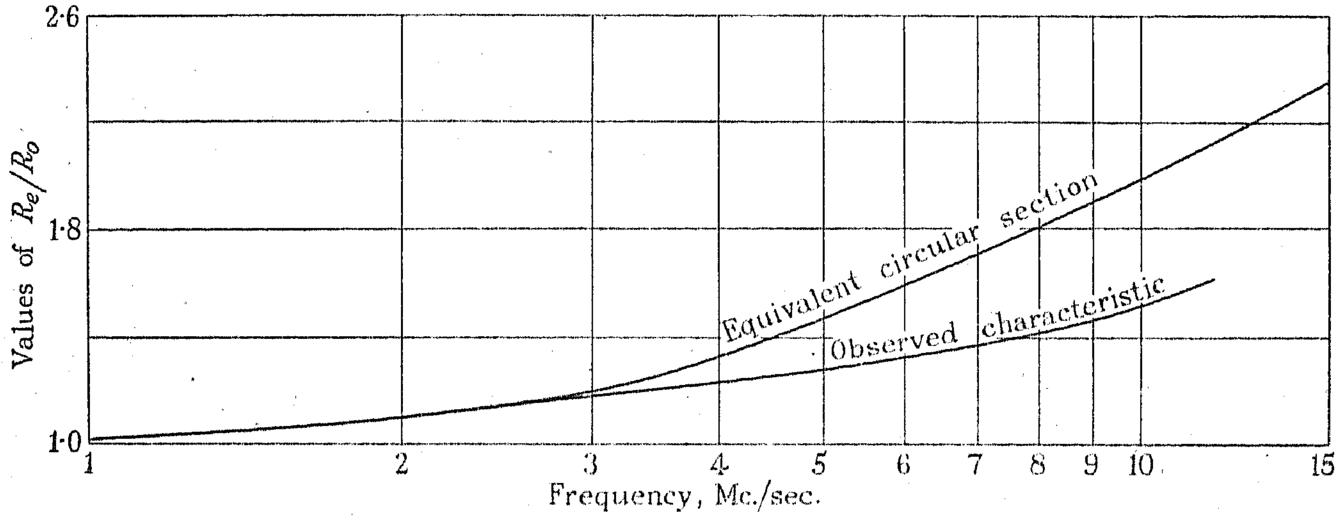

Fig. 11.—Characteristics of Coil A.

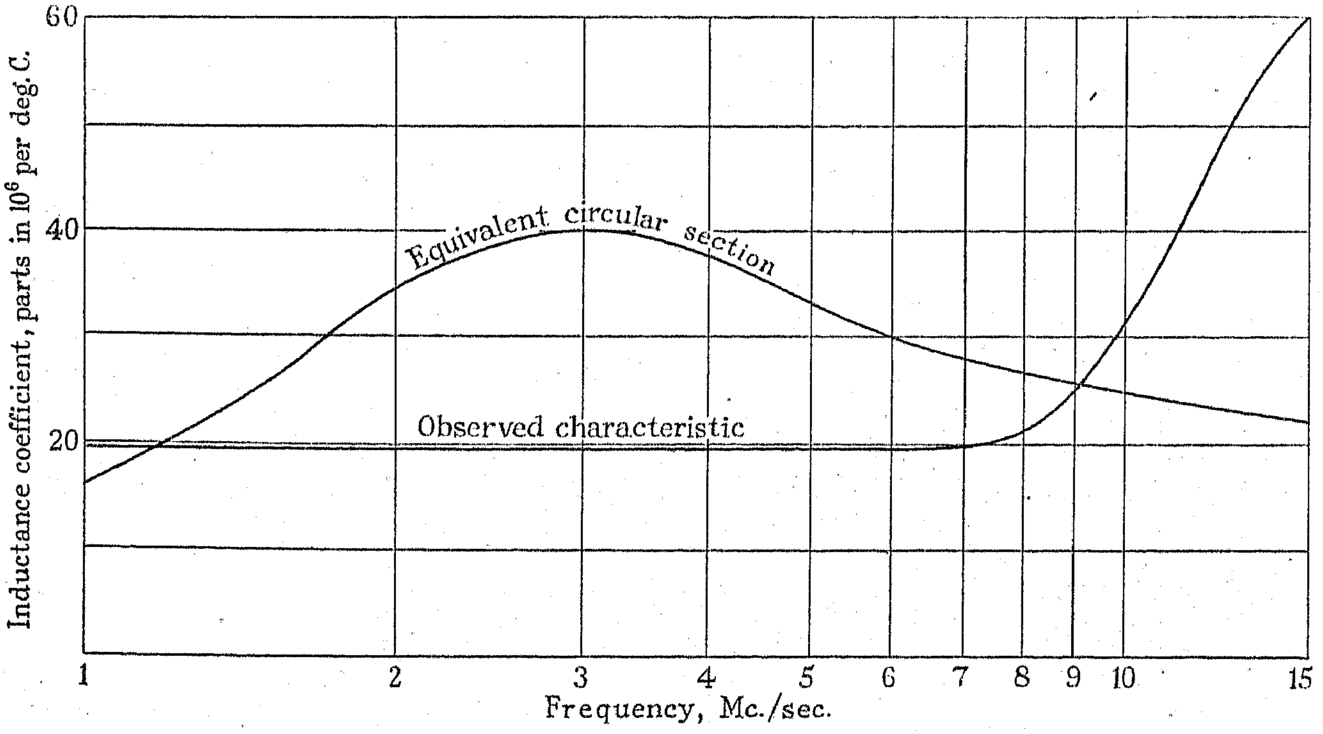

Fig. 12.—Characteristics of Coil B.

Coil A, together with the characteristic for the equivalent circular-section conductor, are plotted against frequency in Fig 10. The radio-frequency resistance characteristic is also plotted in Fig. 11.

It is seen that with such a very thin deposit (0·0076 mm.) the effective resistance increases very little with frequency and the temperature-coefficient of inductance remains constant up to a frequency of about 8 Mc./sec., above which frequency the coefficient appears to increase rapidly. Thus the adoption of the flat-ribbon section has effected a considerable improvement in the constancy of the temperature-coefficient of inductance with respect to frequency, but it is also apparent that a re-distribution of current occurs at the higher frequencies and produces a rapid increase of coefficient. This effect is probably due to the proximity of adjacent turns, the flux from which will tend to concentrate the current at the centre of the ribbon section and so reduce the mutual-inductance component.

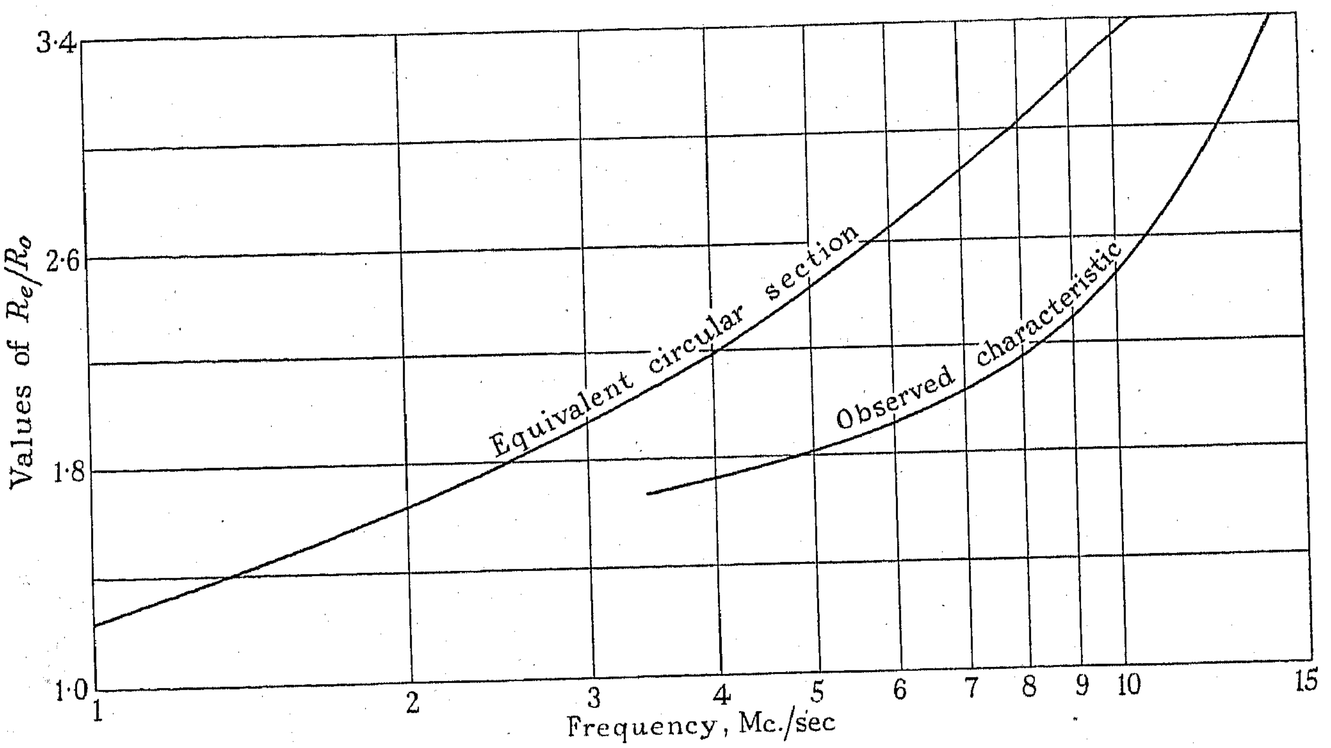

Fig. 13.—Characteristics of Coil B.

The characteristics of Coil B are given in Figs. 12 and 13. In this case the deposit is considerably thicker (0·035 mm.) and the effective resistance increases with frequency to an appreciable extent, but owing to the larger turn spacing the inductance remains sensibly unchanged up to a frequency of about 8 Mc./sec., at which frequency the value of R_e/R_0 is 2·15. It appears, therefore, that a considerable increase of effective resistance can occur before the inductance value is affected, and that the mutual-inductance changes fairly rapidly thereafter owing to a change of current distribution; it is apparent from Fig. 13 that the form of the R_e/R_0 characteristic is essentially different from that of a circular-section conductor.

One unresolved point should be noticed, namely that the minimum value of the temperature-coefficient of inductance for both coils (A and B) is of the order of 20 parts in 1 million per deg. C., whereas the expansion coefficient of the former material is less than 10 parts in 1 million. Approximate measurements have indicated that the expansion coefficient does not exceed this value.

It would appear from these results that to obtain a low temperature-coefficient of inductance which is sensibly independent of frequency, it is desirable to use a conductor of ribbon section deposited flatwise on a former of low temperature-coefficient of expansion. It is important that the turn spacing should be as large as possible, for then an appreciable current re-distribution can occur with frequency variation without producing an appreciable change of inductance. To establish this hypothesis it would be necessary to examine the properties of a number of coils in which the conductor sections were identical but in which the turn spacings were dissimilar. Unfortunately, it is not easy to reproduce a uniform deposit of known thickness in several coils by deposition methods, but it is hoped in the near future to obtain suitable coils by machining. The use of a ceramic former having a negligible coefficient of expansion is also obviously desirable.

(6) ACKNOWLEDGMENTS

The author wishes to acknowledge his indebtedness to the work of Prof. J. Groszkowski, which first called attention to the possible significance of the variation of current distribution with temperature as a factor in the variation of temperature-coefficient of inductance. He also wishes to place on record his indebtedness to Mr. F. M. Colebrook, B.Sc., for consultation in the course of the work, and to Messrs. A. C. Haxton, C. W. Spencer, B.Sc., and R. G. Chalmers, for assistance given in the experimental work.

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THE ELECTRIC STRENGTH OF AIR AT HIGH FREQUENCIES*

By E. W. SEWARD, B.Eng., Ph.D., Graduate.†

(*Paper first received* 20*th July*, 1937, *and in final form* 3*rd November*, 1938.)

SUMMARY

The paper describes a series of experiments on the electrical breakdown strength of air under sinusoidal voltage conditions over a frequency range from 50 to 900 kc./sec. It is shown that with frequencies of the order of 200–1 000 kc./sec. there is a noticeable reduction in the breakdown voltage between spherical electrodes one of which is insulated and the other earthed, the reduction becoming more marked as the frequency is increased. A modification of Townsend's theory,‡ based on a consideration of the ionization conditions prior to breakdown, is suggested, which explains the reduction in the electric strength of a sphere-gap at the higher frequencies.

INTRODUCTION

In the past, various investigators have noticed that the electric strength of air between spheres is reduced as the frequency of the applied voltage is increased.§ F. W. Peek|| states that at high frequencies the breakdown voltage may depend upon some function of the frequency. No experimental evidence is produced, however, to support this statement.

F. Miseré,¶ working with a symmetrical sphere-gap having two insulated electrodes, carried out breakdown tests over a frequency range from 200 to 1 000 kc./sec. His results show a reduction of about 15 % in the breakdown voltage at the highest frequency (995 kc./sec.) compared with the corresponding figure at 50 cycles per sec. This is consistent with the experimental results given in the present paper, though the actual figures are not strictly comparable on account of the different earthing arrangements employed.

Townsend, who investigated the mechanism of breakdown at power frequency, evolved a theory connecting sparkover with corona. The theory is based upon the assumption of a constant electric strength of 30 kV per cm. for air under uniform-field conditions. In the case of non-uniform-field conditions, however, e.g. the sphere-gap, Russell has shown by calculation from observed results that the stress at the electrode surface must exceed 30 kV per cm. before breakdown can occur.** Townsend makes the following assumptions: (1) Ionization by collision occurs from the surface of the corona-forming electrode to a surface where the stress becomes equal to 30 kV per cm. (2) Between this electrode surface and the surface so defined a spark discharge takes place.

The experimental equations of Peek and Russell,†† for determining the relation between breakdown voltage and gap spacing for spherical electrodes at power frequency, are both consistent with these assumptions. It is shown later in the paper that, with slight modifications, this theory can be used to explain the reduction in the electric strength of a sphere-gap, as the frequency is increased, throughout the range under discussion.

DESCRIPTION OF APPARATUS

The apparatus employed for generating the high-frequency voltage consisted of a valve-driven power amplifier coupled inductively to a tuned output circuit.

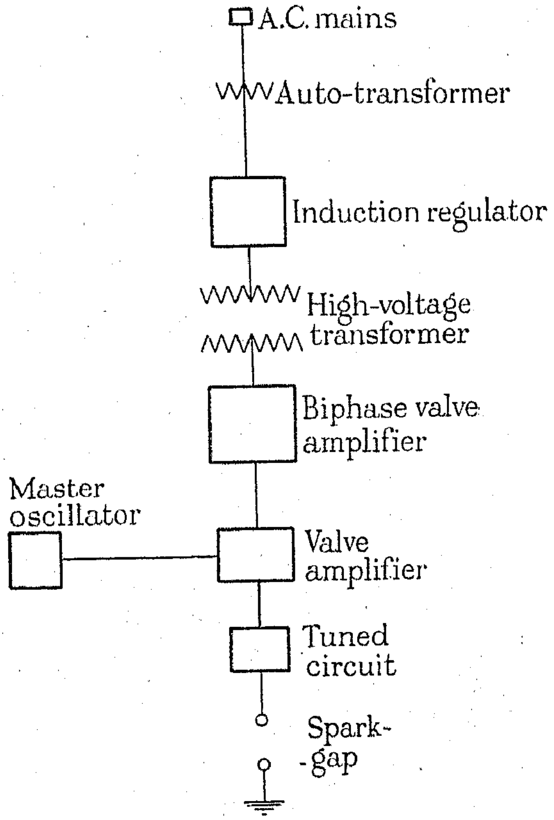

Fig. 1

This latter circuit contained the electrode gap across which the test voltages were applied.

A tuned circuit was used for the output stage, in order to avoid distortion of the voltage wave-form during experiments in which brush discharge preceded the actual breakdown. With this arrangement the harmonics generated by brush discharge are suppressed, owing to the large impedance of the test circuit to frequencies other than the resonant frequency.

The d.c. anode supply for the power amplifier was obtained from a biphase valve rectifier driven from the a.c. mains through a high-voltage transformer. An auto-transformer and induction regulator were included in the primary circuit of this transformer in order to obtain a

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* Reprinted from *Journal I.E.E.*, 1939, vol. 84, p. 288.

† Liverpool University (now with Royal Air Force).

‡ See Bibliography (1).

§ *Ibid.*, (2).

|| *Ibid.*, (3).

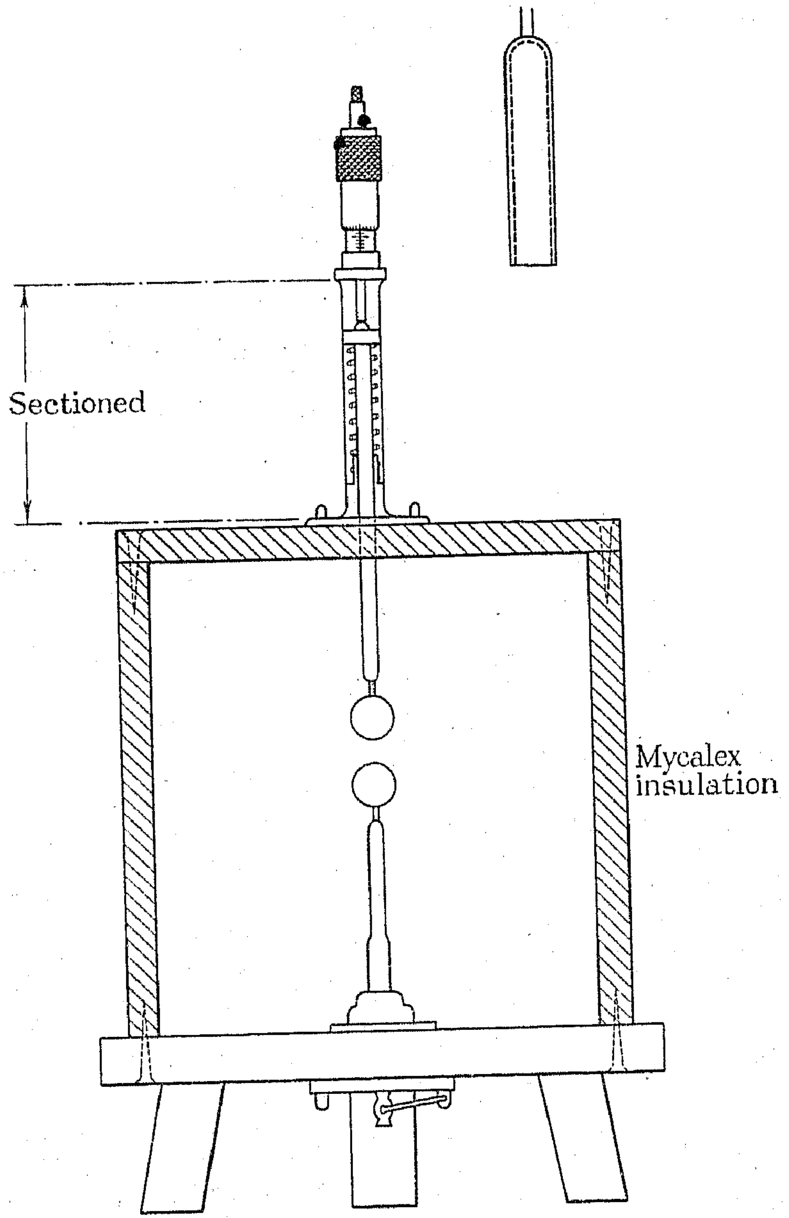
¶ *Ibid.*, (4).

** *Ibid.*, (5).

†† *Ibid.*, (5).

steady rate of change of the voltage applied to the anode of the amplifying valve. This arrangement provides smooth control of the output voltage, as the magnitude of the latter is determined by the d.c. voltage at the valve anode. A line diagram of the circuit is shown in Fig. 1.

The test gap was constructed with mycalex insulation,* the lower electrode, which was at earth potential, being fixed, while the upper insulated electrode was moved by a micrometer screw-gauge, thus enabling very accurate measurements of the gap setting to be made. A sectional view of the test gap is shown in Fig. 2.



Scale: ½ full size.

Fig. 2

As it is necessary to avoid frequency variations throughout the tests, the frequency of the applied voltage was checked at regular intervals by means of a calibrated heterodyne oscillator.

VOLTAGE MEASUREMENT

Voltage measurements were carried out by means of an electrostatic voltmeter in conjunction with a capacitance potential-divider. This arrangement was calibrated at power frequency by means of a high-voltage transformer, the step-up ratio of which had been accurately determined. The divider gives voltage measurements independent of frequency over the frequency range under consideration.*

SOURCES OF ERROR

The figures given in the paper were obtained with a rate of rise of test voltage of approximately 1 kV per sec. A more rapid rate of increase of applied voltage is liable to cause errors of reading of the electrostatic voltmeter, owing to the relatively slow response of this instrument.

Large variations in breakdown voltage may be observed in the presence of fibre and dust particles, and it is necessary to take precautions so as to avoid this source of error. When a potential difference is applied between the electrodes, these fibre and dust particles are drawn into the gap by electrostatic attraction, thus forming partial conducting bridges which lessen the effective gap length and cause breakdown to take place at reduced voltages. With large values of electrode spacing the errors due to this cause are not very important, but with small spacings they may introduce a large percentage error in the measured breakdown voltage.

The proper preparation of the test electrodes is another important factor in the elimination of errors. It has been found that the most consistent results are obtained with clean smooth surfaces, the values of the breakdown voltage being unreliable when visible pitting of the electrodes has taken place. It is not necessary, however, to work with polished mirror surfaces.†

TEST RESULTS

Test results have been obtained with frequencies of 50 cycles per sec., 109 kc./sec., 600 kc./sec., and 900 kc./sec., in the case of spherical steel electrodes of 5 mm. diameter, and with frequencies of 50 cycles per sec. and 600 kc./sec. in the case of 14-mm. diameter spheres. These results are shown in Fig. 3.

THEORY OF BREAKDOWN OF SPHERE-GAP IN AIR

The results given in Fig. 3 show that the voltage necessary to cause sparkover on any gap length decreases as the frequency of the applied voltage increases. This effect can be explained from a consideration of the ionization conditions prior to actual breakdown.

Consider a sphere-gap of which one electrode is earthed while the potential of the other is increasing positively, the maximum applied voltage being just sufficient to cause breakdown at 50 cycles per sec. When the voltage on the unearthed electrode attains a value such as that represented by PQ in Fig. 4, ionization by collision commences, and continues while the voltage is in excess of this value. During the remainder of this half-cycle, electrons will be attracted to and neutralized at the surface of the unearthed electrode A, while the positive ions, which possess a much lower mobility than the electrons, are repelled and form a space charge C near the surface of the earthed electrode B, as shown in Fig. 5(*a*). When the voltage of the unearthed electrode passes through zero and begins to increase on the negative half-cycle, the positive space-charge C is attracted by the negative charge on the unearthed electrode A, thus

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* See Bibliography, (6).

† *Ibid.*, (7).

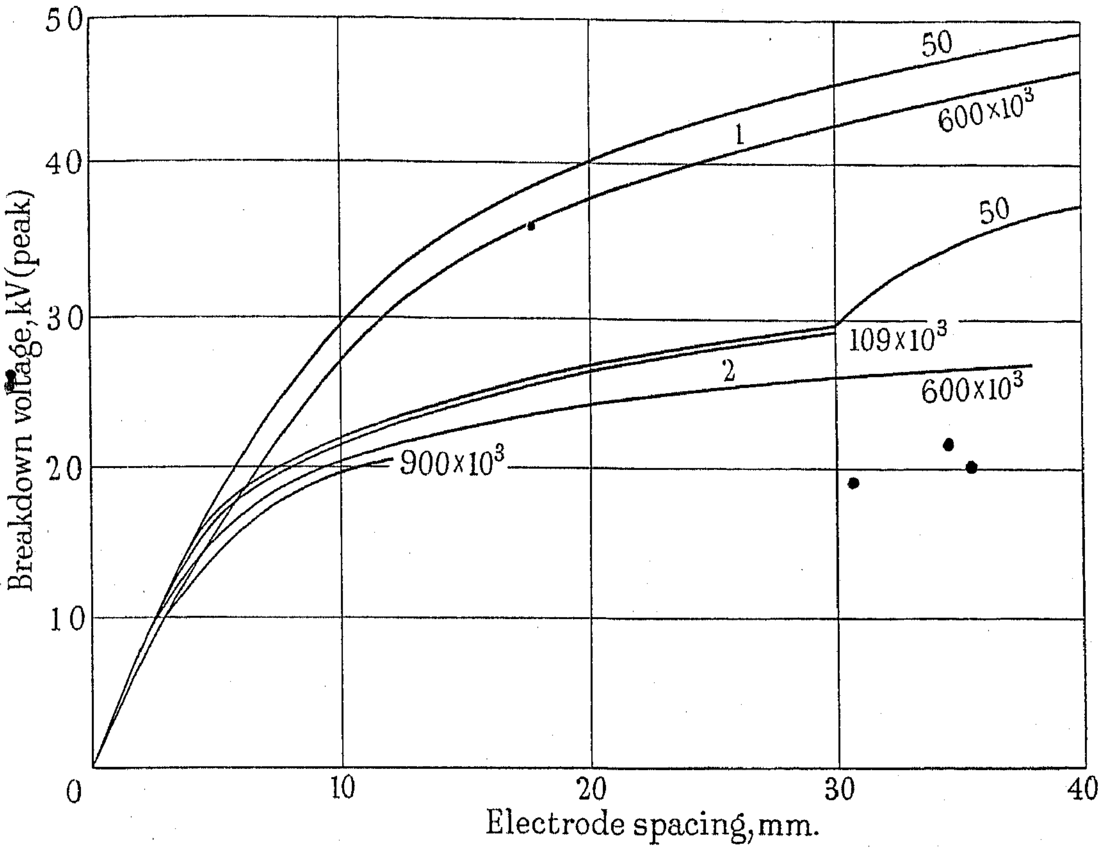

Fig. 3.—Spherical electrodes.

Curves 1. Sphere diameter 14 mm.
Curves 2. Sphere diameter 5 mm.
Figures on curves denote frequency in cycles per sec.

increasing the voltage stress in the intervening air layers between A and C. At some point on the negative half-cycle this stress attains such a value that a discharge passes between the unearthed electrode and the positive space-charge, thus applying the full test voltage to the unbroken air layers between C and B, and complete breakdown follows, unless the electrode spacing is too large.

When the ratio of spacing to diameter exceeds a certain value, depending on the curvature of the test electrodes, a stable brush discharge takes place from the unearthed electrode, and a new set of conditions governs the breakdown of the gap. The brush discharge, as shown in Fig. 5(*b*), is equivalent to an increase in the effective diameter of the unearthed sphere, and complete breakdown follows, according to the above theory, after the brush discharge has been formed. At this spacing, the breakdown is taking place between the earthed electrode and a surface whose radius of curvature has in effect been increased by brush discharge. Thus, at the electrode spacing where brush discharge begins, the curve of breakdown voltage, plotted against length of air-gap, should show a discontinuity of gradient, the gradient changing to a much higher value immediately this spacing is reached. It will be seen from Fig. 3 that the breakdown-spacing curve for 5-mm. diameter spheres, at a frequency of 50 cycles per sec., shows a discontinuity of gradient when the ratio of spacing to sphere diameter exceeds 6. At this and higher spacings a stable brush discharge occurs from the surface of the unearthed electrode.

Brush discharge occurs in nearly all cases only from the unearthed electrode. Electrostatic lines of force emanate from the surface of the unearthed electrode, but a certain number of these lines pass to points at earth potential other than the earthed electrode. Hence a higher potential-gradient exists between the unearthed electrode and the positive space-charge than between the latter and the earthed electrode, and in consequence brush discharge tends to occur, first from the unearthed electrode, followed by complete breakdown. With needle-point gaps, experiments show that brush discharge first occurs from the unearthed point, followed by a less severe brush discharge from the earthed point as the applied voltage is increased. The formation of a stable brush discharge from the earthed electrode in the latter case is due to the exceptionally high potential-gradient existing in the immediate neighbourhood of the earthed point.

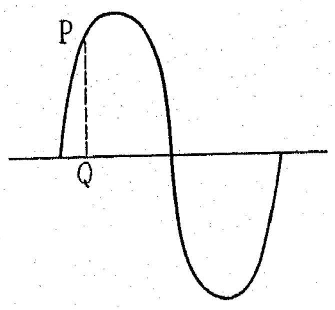

Fig. 4

Experiments with spheres indicate that the voltage gradient between the positive space-charge and the earthed electrode is insufficient to cause brushing, except in those cases where the applied voltage is greater than the critical breakdown voltage of the gap.

It is now necessary to consider the initial ionization conditions when the applied voltage on the electrode gap is less than the critical voltage necessary for breakdown. At the end of one complete voltage-cycle, during which the unearthed electrode is first positive and then negative, the conditions are similar to those described previously, except that the stress in the intervening space between the unearthed electrode and the positive space-charge has not attained a value high enough to cause breakdown. When stable conditions are attained, the positive ions formed during successive half-cycles will be just sufficient to replace those lost due to repulsion. Consequently the positive space-charge will not be augmented during successive cycles, and breakdown will not occur.

EFFECT OF FREQUENCY ON BREAKDOWN VOLTAGE

With a given applied voltage the number of ions formed during a given time will be approximately independent of the frequency, since the formation of ions takes place during the time when the voltage stress exceeds a certain value (PQ in Fig. 4). At all frequencies the numbers of ions produced in a second, for example, will be approximately the same, since the proportion of time during which ion formation occurs is the same at all frequencies.

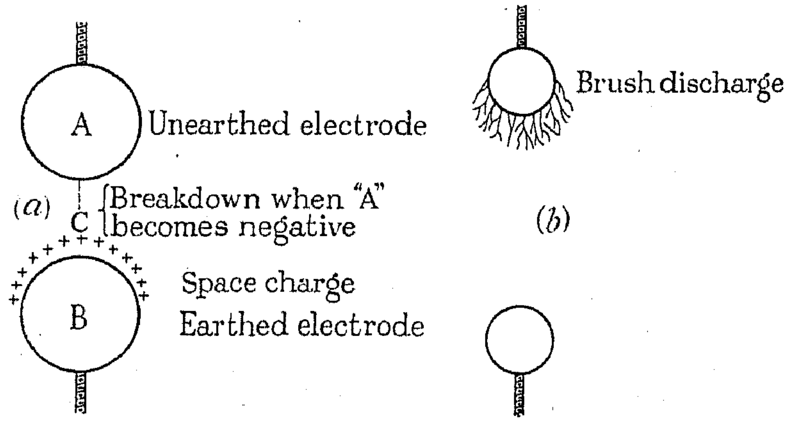

Fig. 5

At high frequencies the ions will be formed in a larger number of short ionizing periods, while at lower frequencies ions will be formed during a smaller number of longer ionizing periods. The number of positive ions lost, however, by electrode repulsion and mutual repulsion will be greater at the lower frequencies, since the " escape " of ions by electric repulsion and mutual repulsion takes an appreciable time before it becomes effective in reducing their number, and there is more time between succeeding cycles at the lower frequencies for the ions to escape or become neutralized before the voltage is applied during the next cycle, and the ionization process continued. The positive space-charge, therefore, is greater at higher than at lower frequency; or, conversely, the voltage at which the number of ions formed is equal to the number of ions escaping is reduced, and therefore the breakdown voltage of the gap is also reduced.

The reduction in electric strength will be proportional to some function of the frequency, and it appears from the preceding discussion that it should be approximately proportional to the frequency. The reduction will be independent of the electrode curvature until a stable brush discharge occurs, when a new set of conditions determines the breakdown of the gap.

These conclusions are borne out by the experimental results. The reduction in breakdown voltage for 5-mm. and 14-mm. diameter spheres is independent of the electrode curvature and is approximately proportional to the frequency, within the limits of experimental error. This is shown by the figures given in the Table.

The reduction in breakdown voltage should increase progressively until the frequency is such that the electrons are no longer able to travel from one electrode to the other before voltage reversal occurs.

Table

VARIATION OF BREAKDOWN VOLTAGE OF SPHERE GAPS WITH FREQUENCY

Frequency (kc./sec.)	5-mm. diam. spheres		14-mm. diam. spheres	
	Electrode spacing (diameters)	Percentage reduction, calculated on 50-cycle results	Electrode spacing (diameters)	Percentage reduction, calculated on 50-cycle results
109	1	1·5		
	2	1·2		
	3	1·6		
	4	1·4		
	5	1·37		
	6	2·0		
600	1	6·8	1	6·8
	2	6·4	2	6·8
	3	6·5	3	6·8
	4	7·6		
	5	9·2		
	6	10·9		
900	1	11·1		
	2	10·4		

SPARK LAG

It has been noticed that with gaps across which the critical voltage has been applied there is occasionally a lag between the instant of the application of the voltage and breakdown. The " spark lag " may vary from a fraction of a second to a few minutes, and can be explained as follows: When the spark lag is of the order of a fraction of a second a certain number of voltage cycles must be completed at the critical voltage before the space charge is sufficient to start the breakdown. Spark lags of the order of minutes may be explained on the assumption that the applied voltage is slightly less than the critical voltage, and that the space charge is slowly augmented by ionization, such ionization taking place below the normal ionization energy-levels. A normal atom may collide with an ion having less energy than that needed to produce ionization, but with sufficient energy to remove an electron from an inner orbit to an outer one. While the atom is still in this state another collision may take place, resulting in the ejection of the electron from the already excited atom. If a number of such collisions occur, the equilibrium between the positive ions formed and the positive ions escaping during successive cycles will be destroyed and the space charge will gradually increase. The spark lag under these conditions may amount to several minutes.

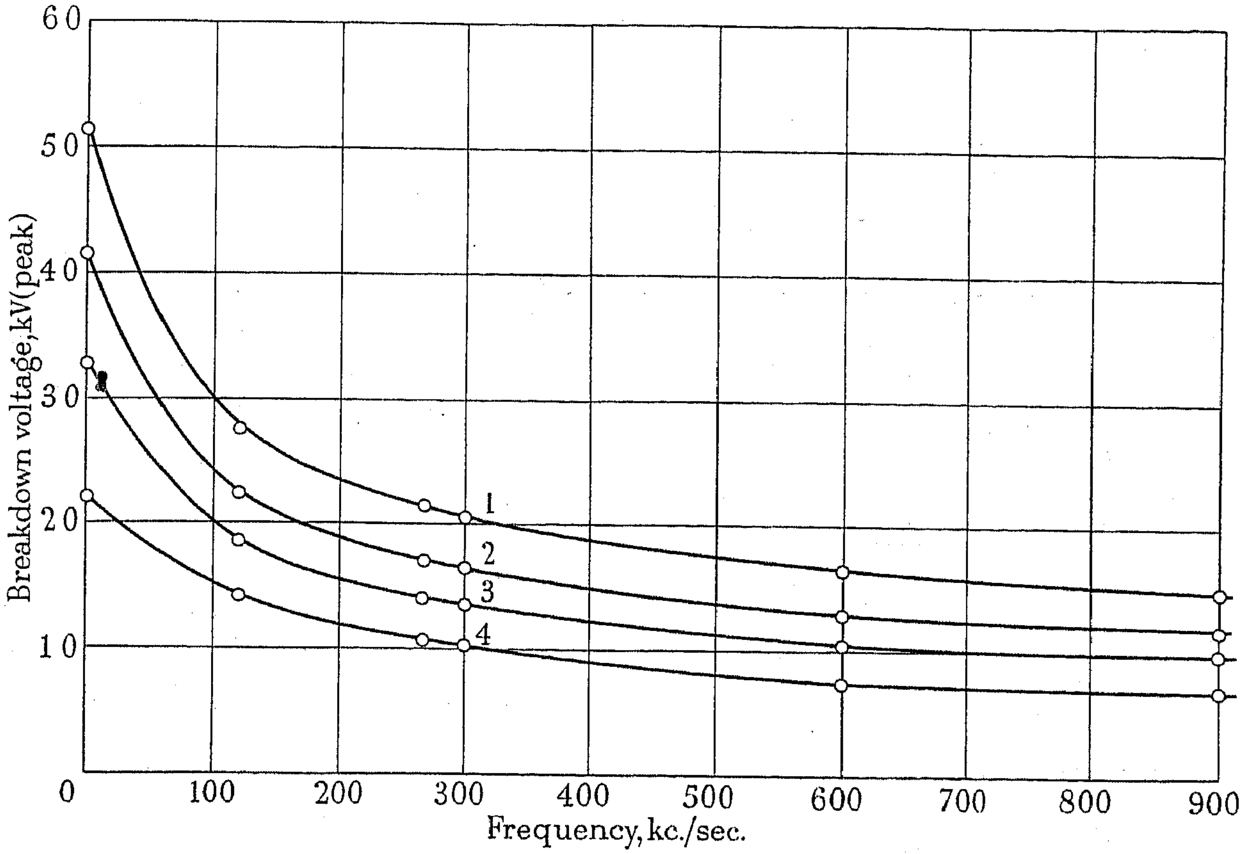

Fig. 6.—Needle-point electrodes.

Electrode spacing
1. 60 mm.
2. 40 mm.
3. 30 mm.
4. 20 mm.

The increased electric strength of sphere-gaps under impulse-voltage conditions is also explained by this theory. If a single voltage-impulse is applied there is no time-interval in which to build up the space charge, and consequently the voltage necessary to effect breakdown is increased.

NEEDLE-POINT ELECTRODES

Tests with needle-point electrodes have been carried out over a frequency range from 50 cycles per sec. to 900 kc./sec., and the results are plotted in Fig. 6.

With needle gaps, brushing invariably precedes breakdown and a different set of conditions determine the rupture of the gap. Again, as the supply frequency is increased, fewer positive ions escape and the intensity of brushing increases. This places an increased stress on the unbroken air layers, and the breakdown voltage is progressively reduced, until the frequency is such that practically no positive ions are lost by electrode repulsion and mutual repulsion between succeeding voltage-cycles. From the curves in Fig. 6 it will be seen that the strength of the needle-gap is approaching this constant value at a frequency of 600 kc./sec., the change in breakdown voltage between 600 kc./sec. and 900 kc./sec. being very small.

ACKNOWLEDGMENTS

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THE LONDON TELEVISION SERVICE*

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SUMMARY

This paper describes a television broadcasting station recently built by the British Broadcasting Corporation in a part of the Alexandra Palace, London, N. The development of the television service in this country is traced from the early attempts to promote an experimental service of transmissions on low standards of definition to the establishment of a high-definition public service.

The paper is divided into six parts.

Part 1 touches briefly upon the history of television development in this country, and describes in some detail the transmission of low-definition pictures from B.B.C. stations during the years 1929 to 1935.

Part 2 deals with the recommendation of the Television Committee that a station for transmitting high-definition television should be established, and it discusses various factors upon which the subsequently appointed Television Advisory Committee based its decisions regarding the choice of the Alexandra Palace site, the operating wavelengths, and standards of definition.

Part 3 describes the arrangement of studios and apparatus rooms at the Alexandra Palace station. The problems of studio acoustics, production lighting, and the provision of essential supplies, are also dealt with.

Part 4 describes the layout and arrangement of the control room and transmitter equipment installed for the vision and accompanying sound transmissions.

Part 5 is concerned with the plant developed to enable current events and other programme items taking place at some distance from the Alexandra Palace to be televised. Some account is given of the use of land lines to carry television signals.

Part 6 is a brief consideration of the reception results of signals from the Alexandra Palace since the beginning of the service, and embodies the result of signal-strength surveys made in the vicinity of, and at distances from, the station.

Finally, the various types of television receivers and aerials are discussed.

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INTRODUCTION

This paper gives a general description of the London Television Station and touches upon past experience with experimental 30-line transmissions. It discusses the circumstances influencing the Television Advisory Committee's recommendations regarding the establishment of a high-definition service, and the subsequent factors governing the choice of operating wavelengths, standards of definition, and the Alexandra Palace site.

Following upon the recommendations of the Television Advisory Committee, the British Broadcasting Corporation has acquired on lease a portion of the Alexandra Palace premises in North London which, with slight modifications, were arranged to accommodate two complete television systems of the Marconi-E.M.I. and Baird companies respectively, each system having its own studio premises and vision radio-transmitter. A third radio transmitter is provided to broadcast at will the sound accompanying the vision of either system. Two aerial systems are provided, the one interchangeable

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between the two vision transmitters, and the other permanently connected to the sound transmitter.

In addition to the premises set apart for present technical requirements, the British Broadcasting Corporation has also leased the Alexandra Palace Theatre, which it is anticipated will provide additional studio accommodation in due course. Certain other areas have been converted into offices for the technical and production staffs.

In the course of the paper the arrangement of the areas referred to above is described and illustrated by means of plans, followed by descriptions of the apparatus installed. The acoustic treatment of the studios and the arrangement of production lighting are described, together with a reference to conditions of working during the production of studio scenes.

An account is given of the equipment developed for television outside broadcasts and of the problems associated with the transmission of television signals over land lines.

The final part of the paper gives an account of the general performance of the station, in so far as this has been ascertained since the inception of the service.

PART 1

EARLY TELEVISION AND THE 30-LINE EXPERIMENTAL SERVICE

(a) Brief Historical Survey of Early Television Activities

Although usually considered to be a modern art which has made accelerated progress in recent years, television has its beginnings deeply rooted in the past. In the case of other similar achievements it is often found that early scientific discoveries have been made for which no immediate practical use could be found, but television differs in that, long before it was contemplated, an accidental scientific discovery clearly indicated the possibility of seeing at a distance.

In 1817 the metal selenium was discovered by Berzelios, and 56 years later an operator named May, working at the terminal of the Atlantic cable at Valencia on the southwest coast of Ireland, discovered that the behaviour of some selenium resistances in use at the station varied according to the amount of light shining upon them through the window. It was, of course, realized that, just as the transmission of sound to a distance by cable necessitates the creation of an electric current which faithfully represents it, so, in order to see at a distance, we must have some means of controlling a current by means of light; and this discovery by May, quickly confirmed by W. Smith and W. G. Adams, created immense interest and may be said to have been the true beginnings of television.

It was clear that television, in common with other methods of transmitting a picture to a distance such as phototelegraphy, required a solution to the problem that the communication channel can be said to have only two dimensions whereas the picture to be transmitted has three. Consequently some means of reducing the three dimensions of the picture to two only were required before television in a practical form could be realized. This was, and still is, accomplished by splitting up the picture into elements which are transmitted successively, and in 1884 the Polish scientist Nipkow invented his famous disc, which is still in use in certain systems of television to-day. Meanwhile other discoveries destined to contribute to the success of television were being made. Faraday in 1845, and Kerr in 1877, had demonstrated the effect of magnetic and electrostatic fields on polarized light. It was not, however, possible to achieve television, as no means of amplifying the very small currents available had yet been found, and therefore a special interest attaches to a description by A. A. Campbell Swinton in *Nature* in 1908 of a device which was the forerunner of the " Emitron " used to-day at the London Television Station. This apparatus fundamentally possesses a comparatively high sensitivity, owing to an inherent electrical storage effect.

During the years 1923 to 1928, experiments carried out by J. L. Baird finally resulted in the completion of a television system which gave tolerably faithful reproduction of an object transmitted through the medium of a line connection between transmitter and receiver.

It was realized that the range of frequencies necessary for the elementary degree of definition then used was only a little greater than was required for the faithful transmission of sound, and it was considered that it might be possible to transmit such pictures over the normal sound-broadcasting system.

(b) The First Regular Transmissions of Television of Low Definition

In 1929, arrangements were made between the British Broadcasting Corporation and Baird Television, Ltd., for the regular broadcasting of television from the B.B.C.'s London station, which was then a 2-kW transmitter situated in Oxford Street. In the system then in use the transformation of the picture into a succession of elements, or " scanning," was accomplished by dividing the picture into 30 vertical strips, or lines, each line being explored in succession by a square aperture, whose width and height were each equal to the width of one line. The number of pictures transmitted per second was 12½, this being achieved by repeating the scanning cyclicly at this frequency. These transmissions, which were unaccompanied by sound, lasted for ½ hour and took place daily except on Saturdays and Sundays, the studio being situated at the laboratories of the Baird Co. in Long Acre.

In October, 1929, these transmissions were transferred to the B.B.C.'s station at Brookman's Park. As this station is equipped with two separate transmitters, one for the National and one for the London Regional programme, it became possible to transmit the sound associated with the television programme, and this was started on the 14th April, 1930.

(c) The Equipment of a Television Studio at Broadcasting House

The British Broadcasting Corporation watched very closely the results of these early experimental transmissions and the progress which was being made at the same time in the laboratories of the Baird Co., and it was decided in 1932 to equip one of the studios in the basement at Broadcasting House with the latest 30-line television apparatus designed by the Baird Co., and to take over the responsibility for originating the transmissions, as by this means more direct experience would be gained of the problems entailed in the production of suitable television programmes.

A studio was therefore set apart in the sub-basement of Broadcasting House, with a small adjoining room having an intercommunicating window between it and the studio. The television scanning apparatus was installed in the adjoining room and operated through the window.

The installation of the apparatus was commenced in July, 1932, and the first programme was transmitted on the 22nd August. The vision signals were still radiated from London National, but the sound signals were radiated from Midland Regional, instead of London Regional from this date.

Fig. 1 shows the layout of the control-room apparatus, from which the various parts of the equipment can be located as described.

The apparatus comprised the following sections:—

(1) The scanning-beam projector for generating the spot of light which is required for the spotlight system.
(2) The photocells.
(3) The amplifiers and mixers.
(4) The caption scanner.
(5) The sound apparatus.

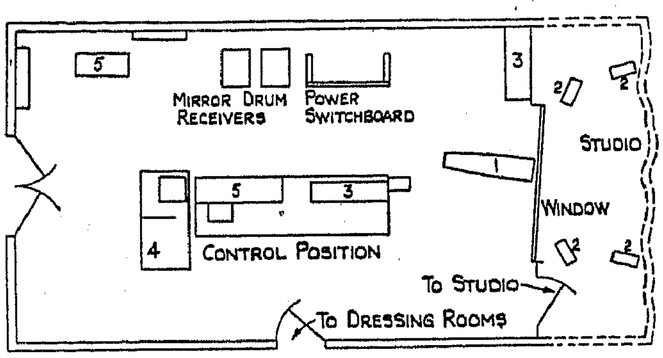


Fig. 1

(1) A schematic drawing of the optical system of the projector is shown in Fig. 2. An arc lamp at B, having its positive carbon horizontal, irradiated an aperture A situated about $\frac{1}{2}$ in. from the positive crater and consisting of a hole 0·125 in. square in a plate of metal.

The light passed to the convex lens L, having a focal length of 22 in., which focused an image of the illuminated square aperture on the artist, via the optical path AL, LP, PM, and MI. P was a plane mirror which reflected the beam on to the mirror drum situated at M. The drum consisted of a metal cylinder having 30 milled surfaces to which were fixed mirrors radially spaced evenly round the drum.

In order to bring the spot into focus on the artist the arc lamp could be moved towards or away from the lens by means of a hand-wheel. The scanning of a very close-up view could not be accomplished by this, however, and when such a view was wanted, the scanned area was reduced in size by an auxiliary long-focus convex lens which could be swung into the optical path in front of the drum, and which is shown at L2.

The projector could be swung horizontally about a fulcrum to follow sideways movements of an artist, and a mask could be raised or lowered to vary the sector of light taken from the drum upwards and downwards to follow the corresponding movements in the studio. Forward and backward movements were followed, as has been explained, by the arc adjustment. The drum was driven by a synchronous motor situated inside it and running at 750 r.p.m. from 50-cycle a.c. mains at 110 volts.

At the end of each line it was necessary to transmit a synchronizing signal, taking the form of a pulse of absolute black which was generated by a mask on the mirror drum which allowed a specific interval at the end of each line. In this interval the photocells received no light, and an electrical black pulse was generated.

(2) The studio was equipped with nine large gas-filled caesium photo-electric cells, and two further banks of four smaller cells per bank. This number of photocells was greatly in excess of that required purely for reasons of sensitivity, but since the photocells must be regarded as light sources from the point of view of illumination of the picture, it was necessary to fit a number to obtain lighting of some artistic merit.

(3) The photocells were connected together to form four groups, and each of these outputs was then applied to its own " A " amplifier, and the outputs of each of these amplifiers were led to a desk, at which an engineer could mix them in desired proportions. It is interesting to note that the operation of these mixing controls had, of course, the effect of varying the intensity and apparent direction of the lighting of the scene.

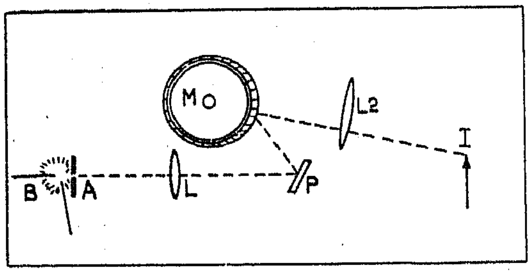


Fig. 2

After passing through the main volume control the signals were further amplified in a " B " amplifier, and thence passed to a pair of " C " amplifiers. One of the " C " amplifiers fed the signals to the main control room at Broadcasting House, from which they were passed by land line to the London National transmitter. The other " C " amplifier supplied a local picture monitor.

(4) In order to be able to transmit titles, tuning signals, and other matter which could conveniently be drawn on a small card, an additional scanner was provided. In this apparatus a spotlight method was again used, light from a 900-watt lamp being distributed by a Nipkow disc on to the card, which was viewed by two photocells. The card was held in place on one of the sides of a dodecahedron made of wood, so that 12 cards could be prepared and brought into position one by one. This subsidiary apparatus had its own individual amplifiers and mixers.

(5) The sound part of the transmissions was picked up by three microphones. The outputs of these were led to mixers, followed by " A " amplifiers. The signals were then sent to the Broadcasting House Control room, from which they were connected by line to the Midland Regional transmitter at Daventry.

Programmes were given four times a week for $\frac{1}{2}$ hour from the above studio, and transmissions included items of varied type, such as variety, ballet, exhibitions of pottery and pictures, and animals from the Zoo.

At the beginning of 1934, as the development of studio technique progressed, it was realized that it would be desirable to have the use of a larger studio. A new studio was accordingly prepared at 16, Portland Place, which adjoined Broadcasting House and was the property of the B.B.C., and on the 16th February, 1934, the transmissions were suspended for 10 days so that the television apparatus could be moved over to the new studio. The programmes were recommenced on the 26th February.

(d) The Cessation of the Experimental Service

Meanwhile, improved systems of television having greater definition and less flicker were being developed, and it was evident that the time was not far distant when the 30-line transmissions would be discontinued. As a preliminary to their discontinuance, the number of transmissions per week (then four) was reduced as from the 31st March, 1934, to two, the length of each transmission, as before, being ½ hour. After a time, however, it was found difficult to produce a balanced programme of general interest in half an hour, and from the 13th October, 1934, these transmissions were lengthened to ¾ hour. They continued in this form for almost another year, after which they were finally discontinued on the 11th September, 1935, in view of the impending high-definition service.

PART 2

EVENTS LEADING TO THE ESTABLISHMENT OF THE ALEXANDRA PALACE STATION

(a) The Television Committee's Recommendations

In order to understand the technical decisions, it is necessary to discuss the circumstances leading to the establishment of the Alexandra Palace station.

Having regard to the rapid strides which had been made in the technique of television, His Majesty's Postmaster-General in May, 1934, appointed a Committee under the Chairmanship of Lord Selsdon to consider the development of television and to advise him on the relative merits of the several systems and on the conditions under which any public service of television should be provided.

Having examined all the different systems of television in this and certain other countries this Committee reported in January, 1935, that the art of high-definition television had reached such a standard of development as to justify the first steps being taken towards the early establishment of a public television service of this type.

In view of the close relationship which clearly must exist between sound and vision broadcasting, the Committee recommended that the authority which is responsible for sound broadcasting—the British Broadcasting Corporation—should also be entrusted with the inauguration of the television service under the guidance of an Advisory Committee to be appointed. Consequent upon the result of its investigations the Television Committee further recommended that there should be an extended trial of two systems under strictly comparable conditions, by installing them side by side at a station in London where they should be used alternately and not simultaneously, for a public service.

The two systems in question were those of Baird Television, Ltd., and Marconi-E.M.I. Television Co., Ltd., both of which were in a relatively advanced stage of development and had already been operated experimentally over wireless channels with satisfactory results. The two companies were therefore to be given an opportunity to supply to the British Broadcasting Corporation the necessary apparatus to operate their systems.

The Committee stipulated that a standard of not less than 240 lines and 25 frames per sec. should be used, as this was considered to represent the minimum definition acceptable for the purposes of a public service.

The Television Committee further recommended that an Advisory Committee be appointed on which the Post Office, the Department of Scientific and Industrial Research, and the British Broadcasting Corporation, should be represented. This Committee was duly appointed and, in turn, deputed a number of its members to form a sub-committee to deal with exclusively technical matters.

(b) The Choice of Standards of Definition and Operating Wavelengths

The respective companies were invited to submit their views regarding the standard of definition which they would prefer to adopt.

Baird Television, Ltd., expressed their preference for the minimum standard acceptable to the Television Committee, viz. 240 lines and 25 frames per sec. sequentially scanned.

For 240 lines and 25 frames per sec. the effective upper limit of frequency generated by scanning was said to be about 1·5 Mc./sec., and it was suggested that any further increase in this frequency band resultant upon an increase in the number of lines or frames was not warranted, on the grounds that the cost and complication of the receiver would be unduly increased. The Marconi-E.M.I. Co. on the other hand desired to use 405 lines and 50 frames per second, interlaced to give 25 complete pictures per sec. They laid stress on the advantages of interlaced scanning on the grounds that it has the apparent effect of increasing the picture-repetition frequency to 50 per sec. at which no flicker is perceptible to the eye. This is achieved, however, without extending the band of frequencies beyond that which would be generated by 25 frames sequential scanning.

The greater number of lines proposed by the Marconi-E.M.I. Co. would of course increase the frequency band, but this, they maintained, would be justifiable in view of probable improvement in receiver technique in the future, which would permit the higher degree of definition transmitted to be effectively reproduced. The upper limit of frequency generated by this method of scanning was said to be approximately 2 Mc./sec.

The Advisory Committee gave the matter of standards close attention, but their efforts to arrive at a compromise in the form of a common standard of definition mutually acceptable to both companies were unsuccessful, chiefly owing to the advanced state of development which had been reached by the companies using their respective standards of definition.

In consequence the Advisory Committee decided that transmissions should take place on both standards of definition alternately. That is to say, during the period of transmission by the Baird system 240 lines and 25 frames per sec. would be used, while during the Marconi-E.M.I. transmission period the alternative standard of 405 lines and 50 frames per sec. interlaced would be employed.

Before reaching this decision the Advisory Committee assured itself that the two proposed standards of transmission could be received on a single receiver by means of a simple switching operation without unduly complicating or increasing the cost of the receiver.

It was hoped that a single radio vision transmitter might be constructed which would be suitable for both systems, but this was found not to be practicable, as the characteristics required by the two systems were so diverse as not to permit of the use of common apparatus other than the aerial and high-frequency feeder line.

Choice of Wavelengths.

The choice of a working wavelength for the vision transmitter was largely dictated by the very wide band of frequencies to be transmitted, as it would clearly be impossible to modulate any but an ultra-short wavelength with such a band of frequencies.

In general it is not practicable to operate a radio transmitter if the ratio of the carrier-wave fundamental frequency to the modulating frequency is much less than 20/1, otherwise the problem of ensuring adequate response at the side-band frequencies becomes too complicated.

This being so, a carrier wave frequency of 40 to 50 Mc./sec. is required for high-definition television, as it is called upon to accommodate modulation frequencies having an upper limit of about 2 Mc./sec.

Above 30 Mc./sec. there are no internationally-agreed wave-band allocations. The Post Office allocated the band between 40·5 and 52·5 Mc./sec. for the purposes of television, and the Television Advisory Committee decided that the London station should radiate vision on a frequency of 45 Mc./sec.

The accompanying sound could, of course from the technical point of view, be transmitted on any wavelength in the short, medium, or long bands, but owing to the congestion which exists, some difficulty would have been experienced in finding a channel for this transmitter, let alone any future transmitter of the same type. Moreover, in the interests of simplicity it is desirable that television receivers should be capable of picking up both sound and vision on one and the same aerial. For these reasons, therefore, the Advisory Committee decided that the sound should be broadcast on an ultra-short wavelength also, as close in frequency to the vision transmission as might be practicable, and a frequency of 41·5 Mc./sec. was chosen for this purpose.

This provided a separation of 3·5 Mc./sec., which was considered to be sufficient to prevent side-band interference between the two signals without encroaching more than was essential on the total wave-band available.

By such a disposition of frequencies, space is left at the higher end of the band for one more clear channel which will serve in the event of the erection of another station. It is believed that in the case of a third station situated more remotely from London, the original London sound and vision frequencies could be used without interference; while in the case of a fourth station, the same frequencies might be employed as for the second station, and so on, allotting the frequencies on a staggered basis. Whether this will be possible is not yet known, as insufficient data have yet been compiled regarding the area of interference caused by the London Television Station under all conditions of ionization of the upper atmosphere. Evidence at present makes it clear that reflection phenomena at 45 Mc./sec. exist, but their full significance is not entirely understood at present. Part 6, Section (*b*), deals with this aspect of the matter.

(c) The Choice of a Site

The choice of a site suitable for the London station presented a number of problems, and it was not an easy matter to find a situation where all the various requirements were adequately fulfilled.

In the first place it was necessary to use ultra-short waves for transmission, for reasons previously outlined. The effective range of ultra-short waves of this order of wavelength is known to be comparatively small—at one time it was thought not to extend beyond the optical range determined by the curvature of the earth's surface, although this has since been disproved. In consequence it is clear that the station must be situated as nearly as possible at the centre of the area of population which it is intended to serve.

Secondly, as is well known, the height of the transmitting aerial above surrounding territory is of cardinal importance in the service area of an ultra short-wave station, so that a most important requirement of the site was that it should stand on high ground and, further, that there should be no restrictions to the erection of a high mast to give a satisfactory elevation to the aerial.

Thirdly, a large area was necessary to accommodate the studios and rooms for the scanning and transmitting apparatus required for the operation of the two systems.

The first and most obvious site for the station is in the centre of the city, but, apart from the fact that no very high ground exists in the centre of London, this situation could not be contemplated, as it would not be permissible to erect a high mast and also the cost of acquiring a sufficient area for the needs of the station would be prohibitive.

Attention was therefore turned to high ground lying some distance from the centre, and a careful study was made of those parts sufficiently elevated to be of interest.

Hampstead and Highgate appeared to offer promise, but it was found that the acquisition of an area sufficient for the purpose in these districts would have been very costly, and severe restrictions existed regarding the erection of high masts.

High ground in the South of London, notably near the Crystal Palace, was considered, but in this case it was felt that the greater part of the service area of the station would be too much displaced in a southerly direction. Such places as Shooter's Hill were ruled out, on the grounds that they were too far from the central residential districts.

The Alexandra Palace site, however, appeared to possess outstanding advantages in that the ground-level was satisfactorily high, being 306 ft. above sea-level. There was a great deal of available space in the building, and Governmental permission to erect a sufficiently high mast was obtainable.

Another factor which weighed in favour of the Alexandra Palace site lay in the fact that the Palace stands on the top of an eminence so that the ground falls away very rapidly in all directions, and is comparatively low-lying all round, particularly in the direction of the centre of London. It was thought likely that this fact would give very low local attenuation, and some experimental evidence bearing upon this assumption is referred to in Part 5, Section (*c*). A 6 in. to the mile relief contour map of Greater London was constructed, and from this it was clear that with this site for the transmitter the number of areas in which weak signals would be likely to be encountered, owing to the overshadowing effect of high ground, would be a minimum over the whole of Greater London.

The Alexandra Palace site was accordingly chosen, and subsequent experience has confirmed the wisdom of the choice. This, however, will be dealt with later in the paper.

(d) The Beginning of the Service, and the Adoption of a Single Standard of Definition

The first transmissions from Alexandra Palace on both systems took place early in August, 1936, and demonstrations were given at the Radio Exhibition at Olympia between the 26th August and 5th September of that year. A period of " trial programmes " followed, and the television service was formally opened by the Postmaster-General on the 2nd November.

It was found that in practice the use of two standards of definition involved many disadvantages, from the point of view both of the manufacture and of the operation of receivers. In response to strong representations from many quarters, the Television Advisory Committee decided that it was essential in the interests of television, and to make possible the simplification and reduction of cost of receivers, to adopt a single standard of working.

It was further found that the impression of flicker associated with the use of 25 frames per sec. sequentially scanned gave rise to criticism on the grounds of eye train, so that the superiority of interlaced scanning at 50 frames per second, giving 25 complete picture scans per sec., was clearly established.

In consequence the Television Advisory Committee decided that transmissions from Alexandra Palace should be carried out on a single standard of definition, viz. 405 lines and 50 frames interlaced, giving 25 complete picture scansper second. A public announcement to this effect was made on the 5th February, 1937.

PART 3

GENERAL DESIGN OF THE STATION

(a) General Plan of the Accommodation

The portion of the Alexandra Palace buildings taken over by the British Broadcasting Corporation consists of the S.E. tower with about 30 000 sq. ft. of adjacent premises in which the station proper is situated. The N.E. tower and theatre comprise a further superficial area of about 25 000 sq. ft.

The S.E. tower was converted to provide offices for the technical, production, and administrative staff, and it also serves as a base for the aerial mast. The existing pylon top and floors were removed, and fire-resisting floors and staircase were installed to provide five floors of offices above the ground floor.

The floors were carried by steel members, and the main brickwork of the tower, which is 85 ft. in height, was tied horizontally by steel ties at each floor, thus producing a structure of great solidity on which the mast could be erected. By means of these alterations the floor area available was increased by some 8 000 sq. ft.

With the exception of the structural modifications to the tower, the premises in general required little alteration from a structural point of view to adapt them for the equipment which they were to contain. Certain additional partitions were required, and it was necessary to segregate the premises from the remainder of the Palace buildings by means of a fireproof partition to fulfil the requirements of the local authorities.

Fig. 3 shows the layout of the S.E. premises. On the ground floor the base of the tower provides an entrance hall which forms the main entrance. Behind the tower is the local electricity substation and distribution switchgear room, the associated transformers being of the outdoor type and situated immediately outside the building.

The premises west of the tower provide two large halls each 70 ft. × 50 ft. to accommodate the Marconi-E.M.I. and Baird vision transmitters respectively, while in a central third hall 56 ft. × 24 ft. is situated the Marconi sound transmitter. Air-blast coolers for the water supply to the cooled-anode valves in all three transmitters are situated on the colonnade in front of the main premises, suitable chambers having been formed by bricking up the existing colonnade arches.

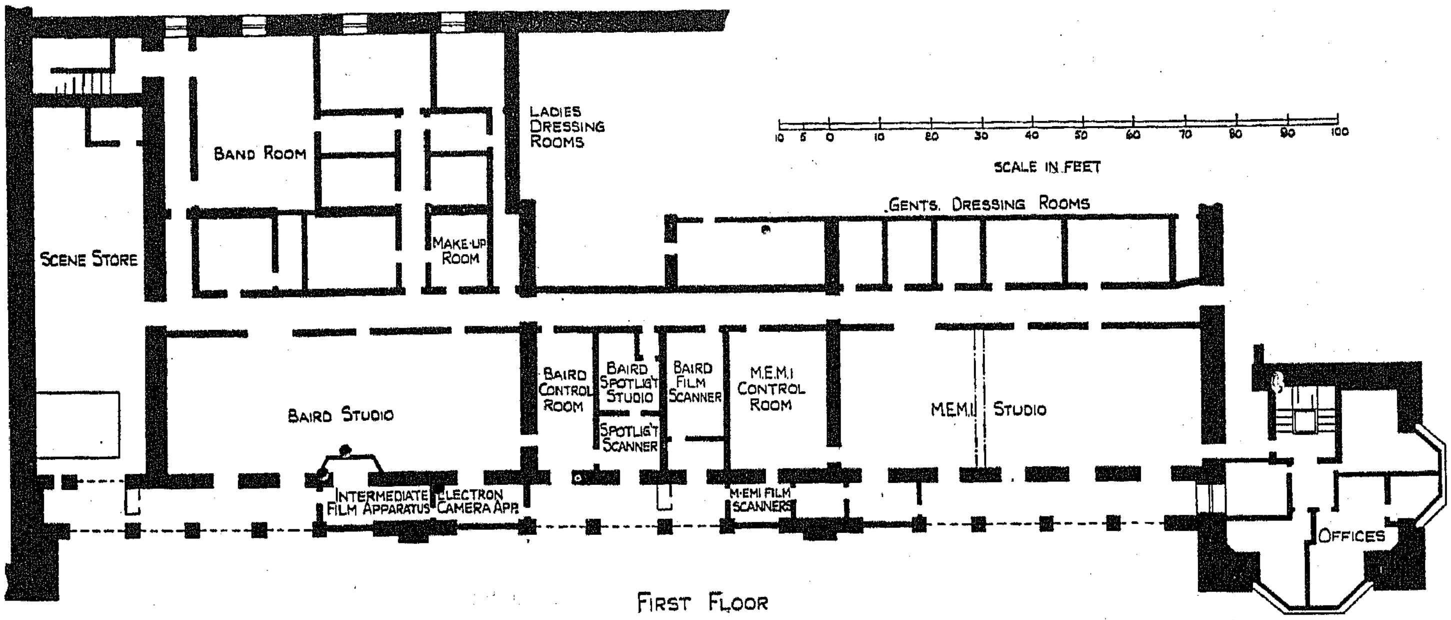
Behind the sound transmitter is a fully equipped theatre 40 ft. × 15 ft. for the projection of sound films, which is used by the productions staff for the selection and timing of excerpts from films which it is proposed to use for television purposes.

At the west end of the ground floor is a scenery-storage space 52 ft. × 22 ft. with a wide and lofty entrance from the terrace, into which large pieces of scenery and other bulky objects can easily be brought. This space can also be used as a temporary studio to televise objects whose weight or bulk precludes the possibility of their being taken to the studios on the first floor. A basement beneath accommodates the boiler for the heating system.

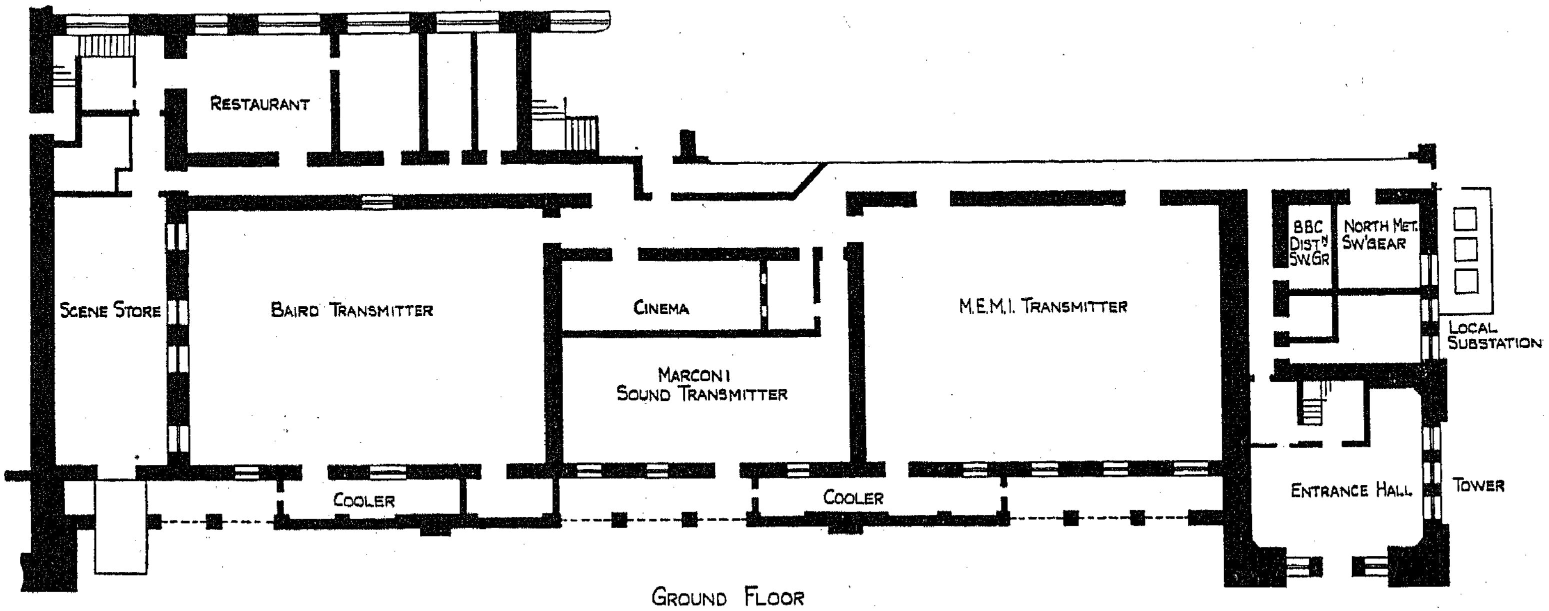
At the extreme rear of the premises is situated a restaurant for the staff, together with the necessary kitchens and storage rooms.

On the first floor there are two main studios each 70 ft. × 30 ft. and 27 ft. high, one for use with the Marconi-E.M.I. equipment, and the other originally used for the apparatus for the Baird intermediate film process and electron camera.

Between the two main studios are two control rooms, one associated with each system, a small studio and scanner room for the Baird spotlight scanning process and a room housing the Baird apparatus for film scanning by mechanical means.



FIRST FLOOR



GROUND FLOOR

Fig. 3.—Plan of London Television Station.

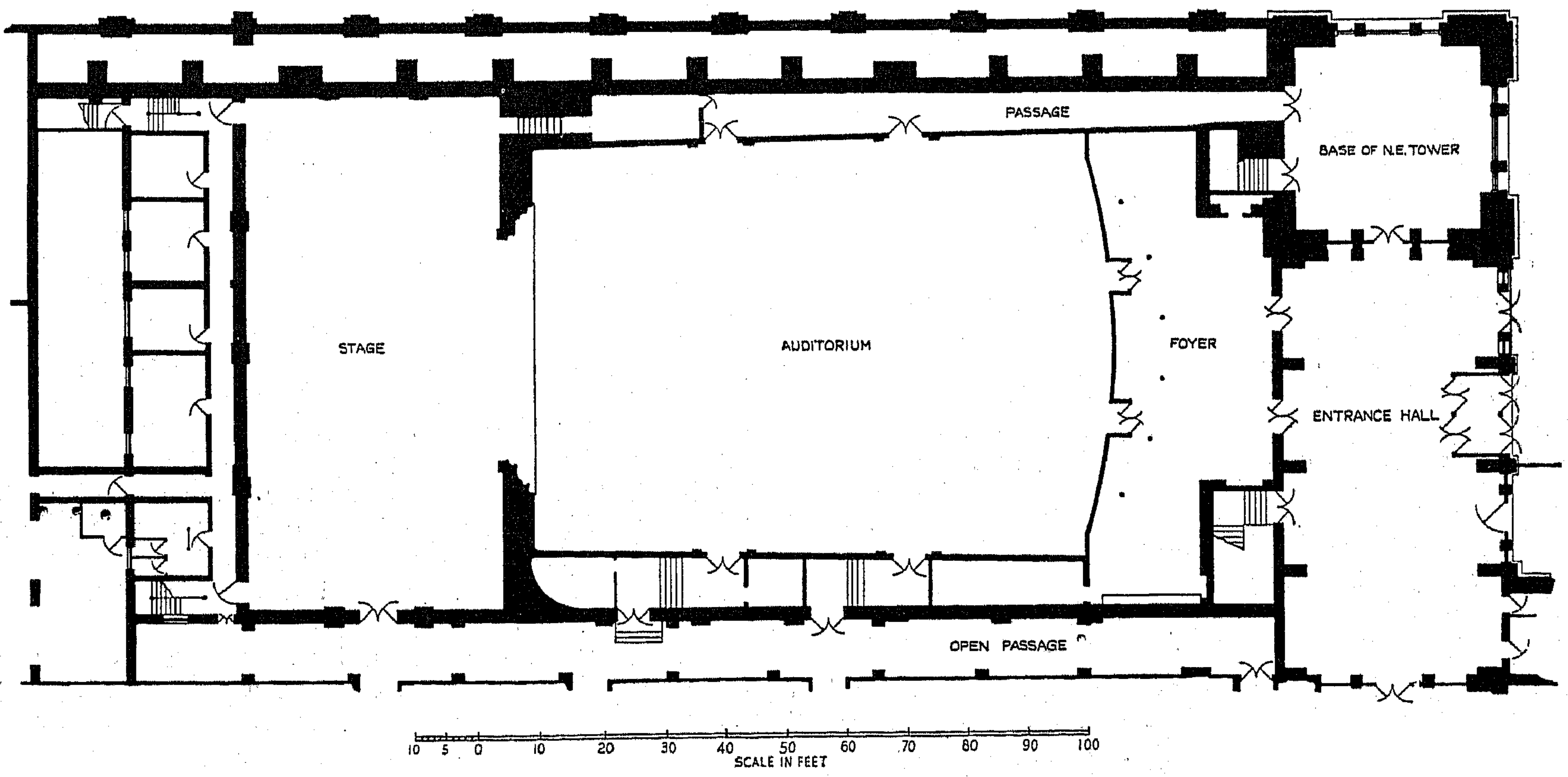


Fig. 4.—Plan of theatre area.

Film scanning by the Marconi-E.M.I. process is carried out in an annexe to the control room, built on the first-floor colonnade.

The rear portion of the premises is devoted to dressing rooms for male and female artists, a make-up room, and a band instrument room. The west end of the premises provides a second scenery store similar in dimensions to and immediately above the store on the ground floor, a floor trap and travelling gantry with block and tackle being provided to raise scenery from the ground floor to the first floor.

The scenery which is required for current productions only is stored in these spaces, the bulk of the scenery being at present stored in the north-east theatre premises.

Since the decision to adopt a single standard of definition, the Baird studio has been brought into use as additional production space for transmissions on 405 lines and 50 frames interlaced.

Fig. 4 depicts the theatre premises, and it will be observed that considerable space for possible future extension of studios exists in this area.

(b) Arrangement of Electrical Supply

The electricity supply for the Alexandra Palace installation is taken from the North Metropolitan Electric Supply Co.'s system. A ring main in the form of two feeders exists between the Alexandra Palace local substation and the Wood Green traction substation via the supply company's substation at Ringslade Road. The Wood Green substation in turn is fed by alternative routes from the supply company's power station at Brimsdown, and thus continuity of supply is amply assured. Supply is at 11 kV, 3-phase, 50 cycles per sec., and distribution is at 415 volts, 3-phase 4-wire, with earthed neutral.

(c) Acoustic Treatment of Studios

As has been stated, the two main studios are 70 ft. long, 30 ft. wide, and 27 ft. high, and their acoustic treatment has called for careful consideration.

It was considered that the acoustic properties desirable in a studio intended for television should differ from those sought after in a studio exclusively used for sound broadcasting.

In the latter case, the ear is the only criterion of the reproduced performance, and the effect produced can be materially enhanced by the artistic introduction of a certain degree of reverberation or echo. Such effects, however, require careful arrangement of the performers before the microphone so that a pleasing balance of sound is obtained. Moreover, the degree of reverberation which is acceptable varies widely with the type of performance —thus a studio suitable for a variety performance would not be suitable for a symphony orchestra, and, in general, different studios are used for different types of programmes. Above all, the placing of the performers from an appearance point of view is a matter of complete indifference in sound broadcasting, so long as a correct sound balance is maintained.

In the case of television, however, it is an entirely different matter, as the proper location of performers from the point of view of appearance is of paramount importance in the interests of artistic production, so that sound requirements must, of necessity, be subservient to this consideration. Added to this, it is not at present economically possible to provide a series of studios of divergent acoustic properties, each fully equipped with the manifold requirements of television.

Consequently, studios designed for general purposes were required, adapted for a wide range of scenic presentations varying from an intimate *tête-à-tête* to an elaborate and extensive production. In order that the sound accompanying scenes of such widely divergent character should be of uniformly good quality, and in the absence of much experience in television technique, it was thought desirable to design the acoustics of these studios on the basis of film-studio technique, that is to say, to make them as little reverberant as possible, and to allow the temporary sets built up as scenery to provide local reverberation for each particular scene. Film-studio practice is to cover as much as possible of the walls and ceiling with a highly absorbent material such as mineral wool. A convenient and less expensive alternative was found in the form of 2 ft. square slabs of asbestos felt about 1 in. thick. The original specification, therefore, was to cover the whole of the wall and ceiling surfaces with this material, stuck in contact with the plaster work. A form of sound-proof shutter was specified for the windows, consisting of a wooden framing, boarded on both sides, pugged with sawdust, and covered on both sides with canvas-covered acoustic quilt. The floor was to be untreated acoustically.

In practice, various modifications were made to this specification. One of the long walls of each studio, that on the north side, was found to be of lath-and-plaster construction unsuitable for direct application of asbestos felt, and it was necessary to support the slabs other than by sticking them to the plaster. To a height of 5 ft. from the floor the walls were close boarded before the application of the slabs. Above this height wooden battens were erected at 2 ft. centres, and the asbestos-felt slabs were nailed to these.

The original lath-and-plaster ceiling was demolished and $\frac{1}{2}$-in. building board was nailed directly to the existing joists. At a later stage, the asbestos felt was found to be easily damaged and it was therefore covered to a height of 10 ft. with a light scrim which appears to have negligible effect upon the sound-absorbent properties of the material beneath.

Fig. 5 is a curve showing reverberation time plotted against frequency for one of the main studios, taken with nothing in the studios but the main fixtures. There is but little difference between the two main studios from an acoustic point of view.

The measurements of reverberation time were taken by means of a piece of apparatus which enables the actual decay of sound to be accurately recorded on a logarithmic scale on a moving strip of wax paper.

In view of the complex nature of the acoustical treatment of the studios in their final form, it is difficult to interpret the curves in relation to the absorbing properties of the various materials employed. Fig. 6 shows the absorption/frequency characteristics, as measured in a reverberation chamber, of asbestos-felt slabs fixed directly to a hard surface and fixed to wooden battens respectively. On the basis of these measurements, reverberation curves rising very considerably for frequencies below 500 cycles per sec. would be expected. Whilst it is probable that for this, as for other materials, some modification has to be made to the absorption curves obtained in a small reverberation chamber in order to render them strictly applicable to a moderately large studio, such modifications would not be sufficient to account for the low reverberation time actually found at these frequencies in the completed studios. It is quite probable that both the lath-and-plaster north wall and the lightly-constructed building-board ceiling are providing considerable low-frequency absorption, while possibly the effect of the relatively large area of window shutters has also to be taken into account. No data are available to enable any analysis of these effects to be made.

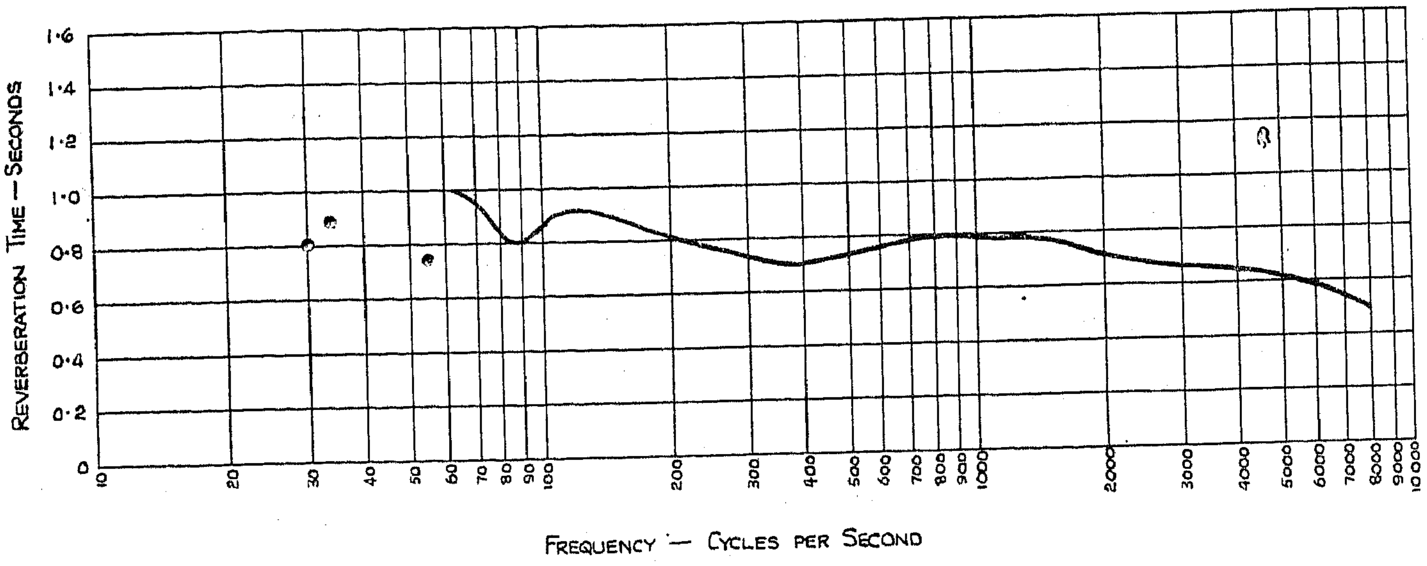


Fig. 5

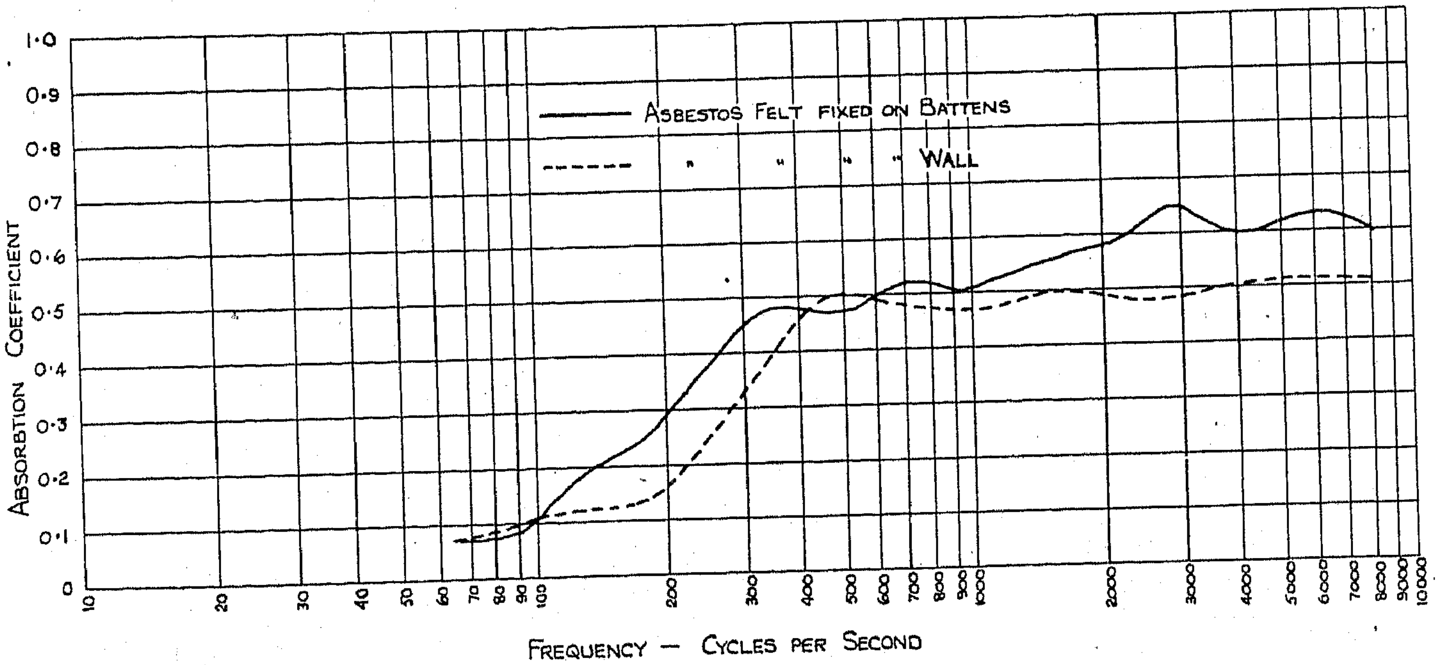


Fig. 6

As a result of the reverberation/frequency characteristics which have been obtained from the finished studio, the quality of the sound broadcast with the television is in general satisfactory over a large range of subjects.

(d) Production Lighting

The lighting of studio scenes for television presentation appears to demand the development of a technique which, while akin to both theatrical and film-production lighting technique and embodying something of both, nevertheless is not exactly similar to either in its entirety.

The reason for this lies in the fact that a television programme is in effect produced before an audience, just as is a stage production, and, consequently, equal continuity of action is necessary. The condition is therefore imposed that the production lighting must, in the main, be on continuously from start to finish, as in a stage presentation; and not intermittently as is usually the case in film studios, where isolated scenes are recorded and afterwards edited and knit together into a continuous whole.

This fact brings several difficulties in its train. First, all production lighting supply equipment must be rated to operate over comparatively long periods; secondly, the projectors and floodlights must themselves be capable of operating for a protracted period without overheating; and thirdly, the ventilation of the studio must be capable of dealing with the continuous dissipation of power involved in high-intensity lighting.

The first point means that it is not possible to economize by specifying a short-time rating for conversion plant and wiring, as is not uncommon in film-studio lighting installations, but rather implies that all lighting equipment must be continuously rated, as apart from the actual use of studios for transmission, a great deal of time is involved in fully lit rehearsals owing to the ever-changing nature of the productions necessary for a day-to-day television service.

The second point means that the design of projectors, spotlights, etc., must be carefully considered with a view to securing extra ventilation and means for conduction of heat generated, otherwise the wastage factor for lighting appliances is liable to be very high indeed.

The question of studio ventilation is covered in a later Section of the paper.

In general, the types of incandescent studio illuminator used for film-studio work have proved equally satisfactory for television, and lens and mirror spotlamps in powers of 500, 1 000, 2 000, and 5 000 watts, together with multiple lampfloods of from 3 000 to 15 000 watts, have all found their place in the television studio.

It has been necessary to modify to some extent the arrangements for ventilation in some types of lamps, as previously remarked, in order to cater for the longer periods of operation involved in television as against the use for which they were originally designed, viz. the film studio.

Arc-lamp illuminators have not been used to any great extent up to the present, chiefly on account of their tendency to give sudden fluctuations in the total amount of light falling on the scene, a feature which is very objectionable from the television point of view. In addition, the fumes from arcs are inconvenient if the latter have to be operated for lengthy periods in any but a very large studio, and arcs also require frequent attention during production.

The supply to all incandescent lamps has been standardized at 110 volts, being the voltage used by almost all film studios, and hence bulbs are readily obtainable in all wattages at this voltage.

The advantages which, in general, have led to the use of 110 volts instead of a higher voltage are manifold. Amongst other things the use of low-voltage high-current lamps has resulted in a smaller filament structure which is more rigid and hence less fragile, and also approximates more closely to a point source.

In order to reduce ventilating problems and give more comfortable working conditions for the artists, attention has been turned to lamps of the water-cooled gaseous-discharge type. Experiments will be carried out to determine the suitability of this type of illumination to television studios, and it is hoped that by a suitable combination of incandescent and gaseous-discharge lamps, the heating effect of close lighting can be materially reduced.

The actual arrangement of lighting units for any given scene in the studio approximates very closely to that adopted for a similar scene in a film studio.

A certain general level of lighting is attained by the use of floodlamps, after which the artists and scene to be televised are lit in detail by means of spotlamps, the exact arrangement and direction of lighting depending a good deal on the nature of the scene. High-angle lighting from the top, back, and sides, is used to give depth to the scene, and modelling achieved by the use of further spotlamps judiciously placed at floor-level. Delicate shading on the features of artists in close-up is achieved in general by the use of low-intensity diffused frontal lighting.

Lighting for television has something in common with lighting for the production of film by some colour processes, in that a fair amount of attention has to be paid to uniformity of illumination. This implies that a good deal of care has to be taken to avoid excessive overlapping of the illumination areas of several spotlamps, because departures from uniformity of illumination so caused while not perceptible to the eye, and often of not much significance when ordinary negative is being exposed, are readily discernible when the scene is viewed with a television camera, much in the same way as they are in the process of photographing colour film.

Studio scenes for television are normally illuminated with an average intensity of about 150 to 200 ft.-candles.

Alternating current is used for the Marconi-E.M.I. studio lighting at Alexandra Palace, and its use does not introduce any flicker into the televised picture, partly as a result of the thermal smoothing of the lamp filaments themselves, but largely because the 50-cycle frame frequency of scanning is so arranged as to be synchronized with the 50-cycle mains supply.

The Baird equipment, on the other hand, operating at a frame frequency of 25 cycles per sec., required the use of direct-current studio lighting for the intermediate film process and electron camera. The necessary supply was obtained from two motor-generators operated from the 415-volt supply mains, giving an output of 300 amperes each at 110 volts.

The detailed arrangement of production lighting equipment in the studios will now be considered.

The Marconi-E.M.I. Studio

The power supply is taken from the main distribution switchgear through a separate feeder and oil circuit-breaker to the primary of two 45-kVA 3-phase transformers, the secondaries of which are arranged for 110-volt 3-phase, 4-wire working. Both transformers are located in the Marconi-E.M.I. vision transmitter hall immediately beneath the studio.

The secondary side of one transformer is connected to a theatre-type lighting switchboard, which controls 24 separate circuits. The circuits are divided into three groups, each group being supplied by one phase and neutral from the transformer. Each circuit has a maximum load of 2 000 watts, and is provided with dimming and pre-selective black-out features.

Bank and differential dimming with any desired combination of circuits can be carried out, and any number of circuits can be pre-set so that they can be blacked out by means of a remote-operated contactor.

The output of the second transformer is taken to an adjacent remote-operated contactor board carrying nine single-pole contactors arranged in three groups of three, each group being connected to one phase and neutral of the transformer. Each circuit thus has a maximum loading of 5 000 watts and is controlled by a push-button switch on the lighting switchboard previously described.

No dimming or bank black-out features are provided in the case of these circuits.

All circuits are run to appropriate positions in the studio and terminate in sockets, to which illuminators may be connected by flexible cables fitted with plugs.

Plugs of different sizes are used for the 2 000- and 5 000-watt circuits so that there is no risk of overloading the former, while the latter can each be loaded to capacity either by the use of a single 5 000-watt illuminator, or by a number of lamps of lower power attached through the medium of multiple adaptors.

Fig. 7 shows the arrangement of the lighting appliances in this studio, from which it will be noted that the acting space is concentrated towards the eastern end. The area at the opposite end accommodates the orchestra and affords a certain amount of working space.

Extending around the three sides of the acting space bounded by studio walls is an erection of builders' steel scaffolding, which forms a lighting gallery at a height of 14 feet. This gallery is continued in the form of a bridge of steel-lattice construction, across the studio in front of the acting space.

The extreme flexibility of the steel-scaffolding construction is of manifest advantage, as extensions can be quickly fitted wherever necessary and illuminators clipped on by means of a fitting developed for the purpose at any height or angle to meet the requirements of some particular production.

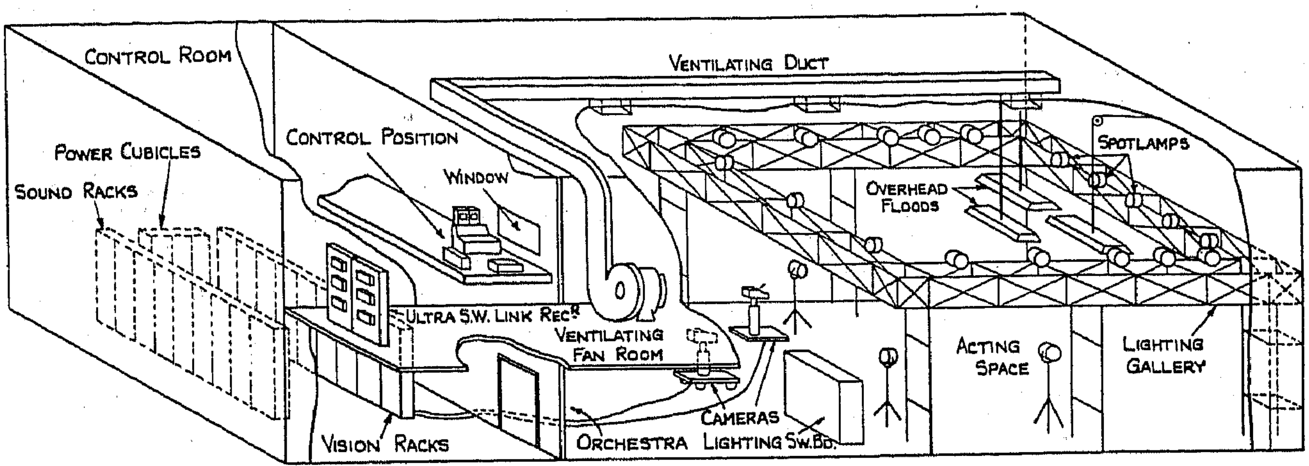


Fig. 7.—Diagrammatic layout of studio and control room, showing arrangement of production lighting.

The majority of the supply plugs are situated at lighting gallery level, as the bulk of the lighting power is concentrated in illuminators giving high-angle lighting. A number of overhead battens are provided, which can be lowered to floor-level for fitting up, and which serve to support the multiple-lamp floods used to afford the necessary diffused general lighting. These battens are provided with a number of circuits fed by flexible cables hanging from the ceiling and terminating in plugs on the battens themselves. Fig. 8 (see Plate 1, facing page 48) depicts a typical studio production scene.

The Baird Studio

The lighting arrangements in this studio are very similar to those in the other, and there again the system is divided into two parts. A theatre-type switchboard controlling 30 2 000-watt circuits is installed having identical facilities with that installed in the other studio, except that the supply is obtained from the two 300-ampere motor-generators previously described.

The second part of the system consists of a 45-kVA 3-phase transformer with 9-way remote-operated contactor board, situated in the Baird transmitter hall, feeding nine 5-kW distribution sockets in the studio, all arrangements being identical with those previously outlined for the similar portion of the equipment in the other studio.

The practice of mixing d.c. and a.c. studio lighting may, on first sight, appear unusual, but there is no valid reason why it should not be done, as the two parts of the system are entirely separate.

The layout of the studio differs but little from that depicted in Fig. 7, except that the lighting bridge traversing the studio is omitted. The arrangement of steel scaffolding for back and side lighting galleries is precisely similar in both cases.

(e) Studio Ventilation

The ventilation of a television studio is a matter which requires some consideration and, in general, involves problems which are not met with in the broadcasting studio and probably only to a lesser degree in the film studio.

In order to ensure adequate ventilation it is necessary to change the air in the studio with sufficient rapidity to carry away the heat due to production lighting without the introduction of noise from the ventilating machinery, which would be picked up by the studio microphones.

In the broadcasting studio the question of noise is of course equally important, but the absence of intense lighting, involving large dissipation of power, materially eases the problem, because the number of changes of air required per hour are very much fewer.

In the average film studio the ventilation problem is in general easier than in the present Alexandra Palace studios, because of the shorter times during which full lighting is in use, and also because of the greater volumetric contents of the average film stage. The particularly significant factor in this is the great height which is usually encountered, and which allows heated air from the lighting to rise to the top part of the chamber, where it accumulates during the shooting of a scene and is gradually removed by the ventilating fans during the subsequent period when no lighting is in operation.

In these circumstances the air at floor-level normally remains fairly cool, and continuously-operating ventilating machinery of moderate proportions proves quite adequate to exhaust the periodically replenished accumulation of heated air.

Ideally, of course, the studio should be provided with conditioning and refrigerating machinery in addition to the mechanism for changing the air, so that when the outside temperature is high in summer, the incoming air may be rendered quite clean and cool before its introduction into the studio. In the case of the Alexandra Palace installation no refrigerating machinery is provided, as it was felt that it was justifiable to dispense with it on economic grounds.

Each studio is provided with a separate ventilating system, the two equipments being similar in construction and disposition. Ventilation is effected by extracting the heated air from the upper part of the studio through three square grilled openings situated on the centre line of the ceiling and equally disposed along the length of the studio.

These outlets are connected by sheet-metal trunking, lined with acoustic board to minimize the transmission of noise, to a centrifugal fan capable of a maximum continuous duty of 10 000 cu. ft. of air per minute, giving approximately 12 changes of air per hour. The fan is driven by a 3-phase commutator motor with movable brushgear, giving a speed variation of 200 to 960 r.p.m.

The brushgear is controlled, through the medium of wire ropes running over pulleys, by means of a handwheel situated in the studio, and the speed variation so afforded gives adequate control of ventilation over a large range of lighting loads and conditions of outside temperature.

The incoming air to each studio is drawn from the colonnade through a series of specially constructed inlets, these taking the form of acoustic labyrinths designed to allow free passage of air while minimizing the ingress of sound from the outside.

The method of ventilation adopted differs from that used in the sound studios at Broadcasting House, as in this case conditioned air is introduced at the top of the studios and the displaced air allowed to escape through openings at the bottom. The object of this procedure is to avoid as far as possible the creation of draughts.

In the case of the Alexandra Palace studios, however, so much heat is generated by production lighting that it would not be satisfactory to oppose the resultant strong convection currents of heated air by artificially reversing the natural direction of air circulation.

(f) Studio Development

Some attempt will be made in this Section to forecast the general lines upon which the development of studios is likely to take place. It must be made clear that the following is based on proposals which are at present receiving consideration but in regard to which no definite decision has been made.

It is desirable when contemplating the extension of production facilities at Alexandra Palace to have continually in mind the requirements of extensions in the more distant as well as the immediate future. At present there are, as has been stated, two main studios of equal size, both equipped with comprehensive lighting systems, and under existing circumstances both these studios are operated from a single control room which provides facilities for the operation of four studio cameras and two film-scanning cameras simultaneously. The bulk of the production at present takes place in the east studio (the Marconi-E.M.I. studio) and the west studio (originally the Baird studio) is used as an annexe for further productions on occasions when requirements exceed the capacity of the east studio. Moreover, the control-room apparatus is so arranged that simultaneous working in both studios is not possible, and considerations of space in the existing control room preclude the possibility of extending the apparatus sufficiently to permit of this facility.

It is clear that only one actual transmission can be carried out at any one time owing to the existence of but one vision transmitter, but, nevertheless, it would be advantageous if a locally viewed televised rehearsal could be conducted in one studio while the other was on transmission, or, alternatively, simultaneous rehearsals conducted in both studios.

A further advantage would be gained by increasing the number of studios to three, and it is desirable that the third studio should be a good deal larger than those at present existing. The Alexandra Palace theatre has much to commend its use in this connection, as the available floor space is many times greater than that of the present studios, and experience has shown that the area of these is insufficient to permit of convenient working when productions of any magnitude are carried out.

The exact manner in which the studios would be arranged from the point of view of the television apparatus calls for very careful consideration, and it is essential that each should form part of a cognate scheme of working, which, although it might not be possible on economic grounds to complete it at one time, could be gradually built up as time went on.

Such a scheme has therefore been drawn up. It provides that each studio should be a complete unit with full production and rehearsal facilities, provision of film-scanning apparatus, and everything necessary for the production and monitoring of a televised performance or rehearsal, with accompanying sound.

The outputs from all studio units would then be brought into a central control room where facilities for pre-viewing the picture and pre-hearing the sound from each studio would be available, and a master-control position would be established. The master-control position would be provided with means for fading from one studio to another, both vision and sound as required, or making such superimpositions or dissolves as might be necessitated by the nature of the programme.

A further function of the proposed central control room would be to carry out the introduction into the radiated programme, at appropriate times, of television outside broadcasts coming from points remote from Alexandra Palace. The question of these outside broadcast transmissions is dealt with later in this paper.

In addition to the central control room, it is considered desirable that a centralized synchronizing signal-generating equipment should be provided, so that all sources of vision signal local to Alexandra Palace would be supplied with synchronizing impulses from a common source and superimposition of one upon the other could be carried out without difficulty.

PART 4

DESCRIPTION OF EQUIPMENT

(a) Marconi-E.M.I. Studio Equipment

This paper is not intended to include a detailed technical description of the apparatus; consequently, attention will be directed towards its operation rather than its principles of design.

The Marconi-E.M.I. system centres around the Emitron transmitting tube, which is a photo-electric device incorporating a light-sensitive mosaic scanned by means of an electron beam. Emitron tubes are built into portable cameras resembling, and used in a similar manner to, motion-picture cameras.

The Marconi-E.M.I. studio is equipped for the transmission of vision with four such cameras and their associated circuits. In addition, for the transmission of film which may either be required separately or as a composite part of studio production, there are two sets of film scanning apparatus in which the film is reproduced by a standard motion-picture head mechanism, the resultant image being projected through a suitable optical system directly on to the mosaic plate of an emitron tube, contained in a camera which in other respects is similar to those used for studio purposes. The sound is reproduced by means of a sound head of conventional design. A detailed description of this device is given in another paper.* There are, thus, in all six cameras, all of which are identical as regards their design and that of their auxiliary apparatus.

With each camera is associated a camera channel, which is a chain of apparatus enabling the control to be effected of all variables associated with each individual camera. These include the intensity and focus of the Emitron scanning beam, the width, height, and exact location of the scanned area, the tilt and bend wave-forms which are injected for the correction of illumination errors, and the gain of each channel. There are also controls which take account of the finite time of transmission of the scanning wave-forms and vision signals along the camera cables, which transmission times will, of course, vary with the lengths of cables in use.

It is desired to be able to transmit any one of the pictures emanating from the six cameras, or in some cases more than one simultaneously, this being known as superimposition and being a favourite presentation device. It is a fundamental principle of presentation technique that more than one camera should be used in a studio production, the transmission being frequently changed from one camera to another in order to increase production facilities, and it is therefore desirable to be able simultaneously to observe the picture derived from any camera not on transmission so that all the necessary technical adjustments may be made before it is introduced into the transmission.

To accommodate these requirements of the London Television Station, three groups of apparatus known as "picture channels" are provided, which are linked with the six camera channels by means of an intermediate unit known as the "fading and monitoring mixer." By means of this unit the picture from one or more cameras may be introduced into the transmission and simultaneously observed upon a viewing monitor. At the same time the picture from any other camera may be connected to the second picture channel and a preview thereby obtained on a further viewing monitor associated with this channel. The third channel fulfils two functions. It enables the transmissions of film which are made every morning for the benefit of the radio industry to be carried out without interfering with a rehearsal which is proceeding at the same time, and which is using the other two picture channels. At other times it constitutes a spare channel.

The transmission of the sound associated with the programme is catered for by the provision of five moving-coil and three ribbon microphones in the studio. In addition there are, of course, the sound heads of the two telecinė projectors, and there are two gramophones by means of which interval music and effects may be introduced. Each of these 12 sources has its own pre-amplifier at the output of which the signals are in all cases approximately at zero level. After control at the sound-control desk, which will be described later, the signals pass into main amplifiers, and thence by distribution circuits to the transmitter and to subsidiary amplifiers for the operation of various monitoring loud-speakers.

This equipment, together with its associated H.T. and L.T. supply apparatus, is mounted in three rows of bays on the ground floor of the control room adjoining the studio, as shown in Fig. 9 (see Plate 2). The control room is 30 ft. long, 22 ft. wide, and 24 ft. high. At a distance of 15 ft. 6 in. from the ground a gallery is provided with a window looking into the studio. Behind this window are grouped a number of control positions from which the presentation of the programme can be handled. In the centre sits the producer and the senior studio engineer. In front of each is a microphone by means of which instructions may be given to the camera operators, the studio sound engineer, the electricians, and the studio manager, all of whom are provided with headphones. By means of a row of control keys such instructions can be given to any of the above engineers singly, or by depressing a master key to all those provided with headphones. Behind the producer sits the vision mixer, whose function is to introduce the various cameras into the transmission as required by the producer. In front of the producer is the sound-mixing desk, which receives the inputs from the 12 sound sources. The desk is operated by the sound mixer who, as in the case of the vision mixer, introduces the various sound sources whether they be microphones, gramophones, or film sound-tracks, into the transmission as directed by the producer. The sound-mixing desk is provided with separate balancing and fading controls. By means of the former the level of any sound source can be adjusted to the correct value, so that it can be rapidly introduced if required by operation of the fade control. Adjoining the sound-mixing desk is the sound-control position, at which the volume of the sound sent to the transmitter is manually adjusted. The control gallery also carries the gramophone position, so that its operator is in easy touch with the producer. There are also provided a pair of viewing monitors, one for the transmission and one for the preview circuit, and a loud-speaker so that the producer and all the engineers on the control gallery can

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* C. O. Browne (see page 74).

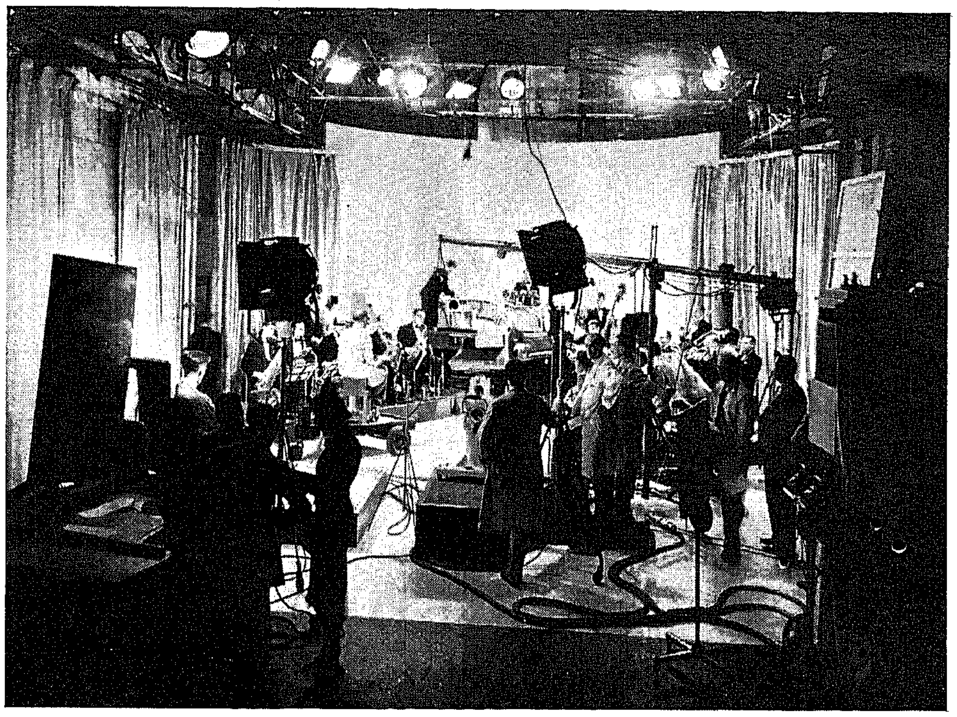

Fig. 8.—Studio scene during rehearsal.

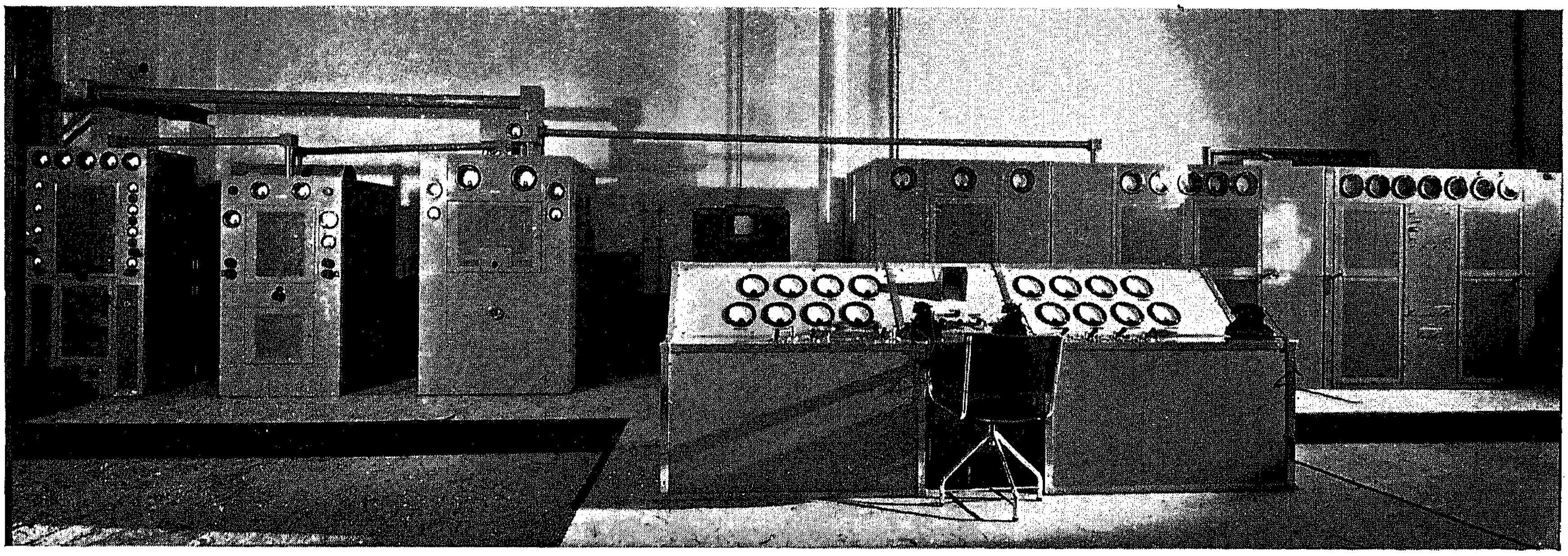

Fig. 10.—Vision transmitter.

Radio apparatus on left; modulator on right; control table in foreground.

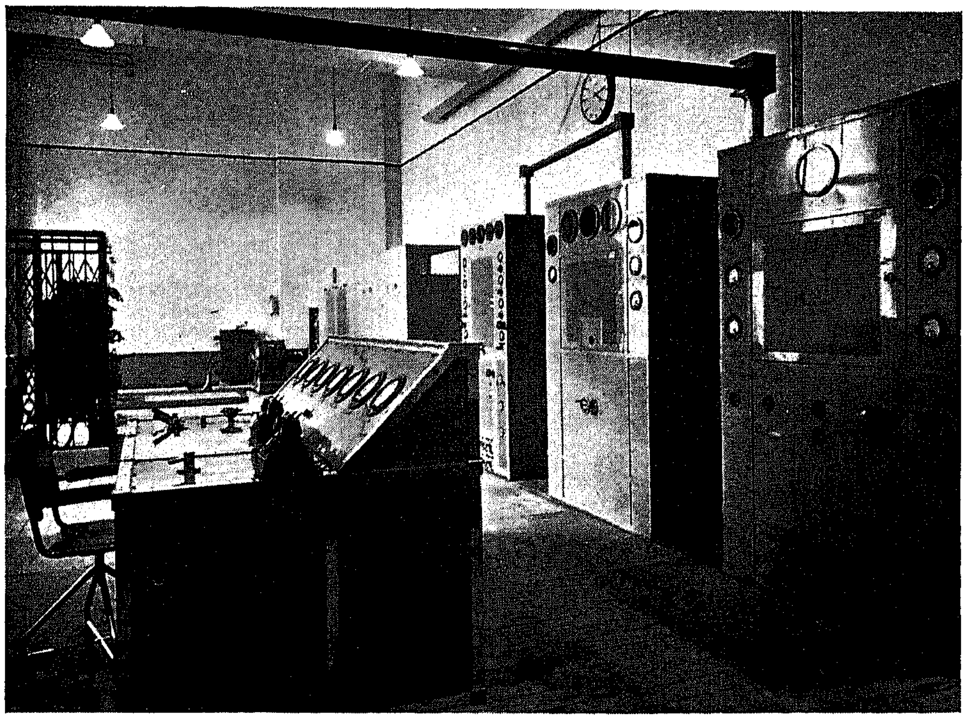

Fig. 11.—Sound transmitter.

Left foreground—Control table.
Centre background—Drive unit and low-power high-frequency stage.
Centre right—Final power amplifier.
Right-hand side—Modulator unit.
Left background—Power switchboard.

(*Facing page* 48)

Plate 2

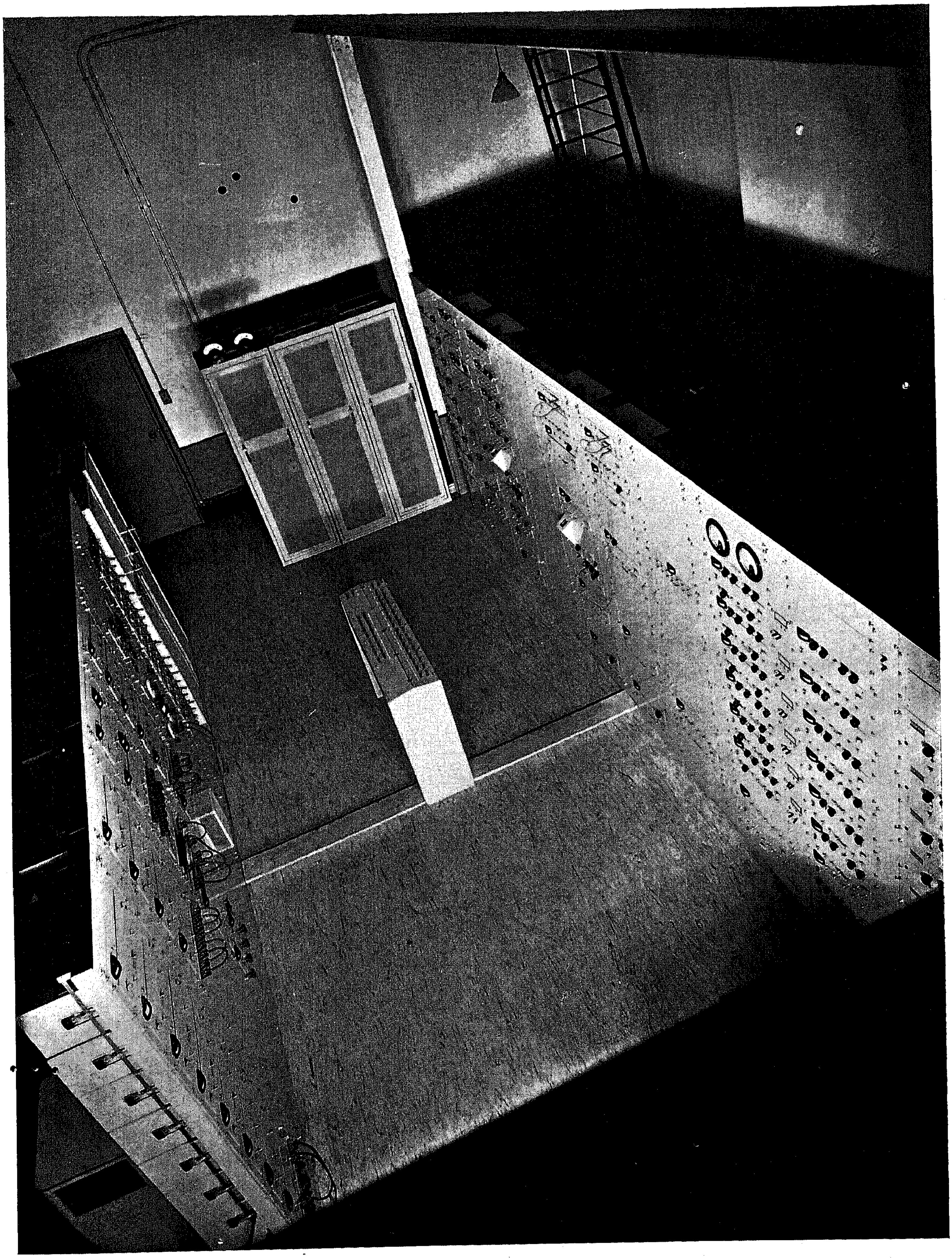

Fig. 9.—Control room of Marconi-E.M.I. system.

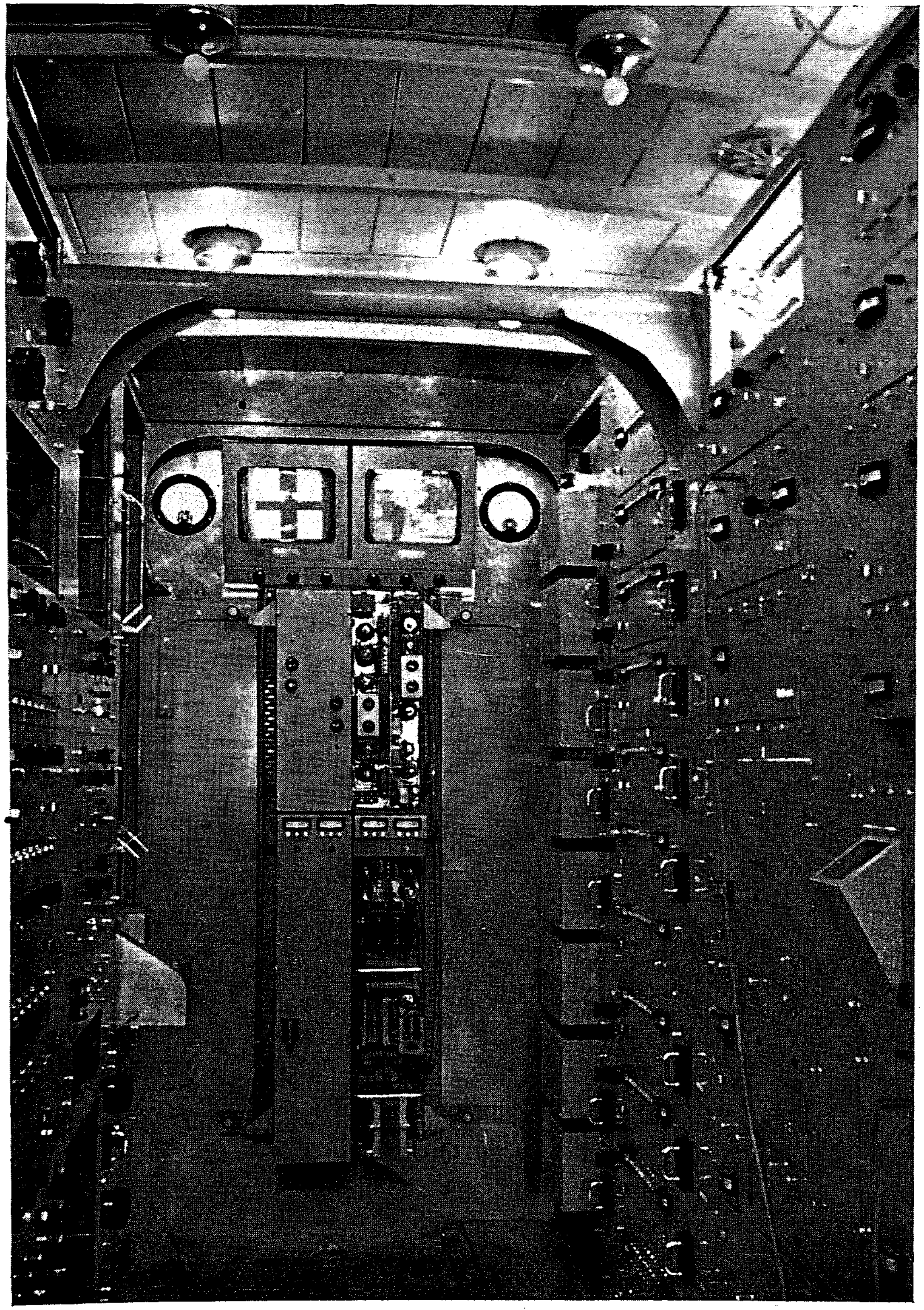

Fig. 12.—Mobile television control-room, showing picture monitors.
At right-hand side—Pulse generating equipment.
At left-hand side—Camera panels.

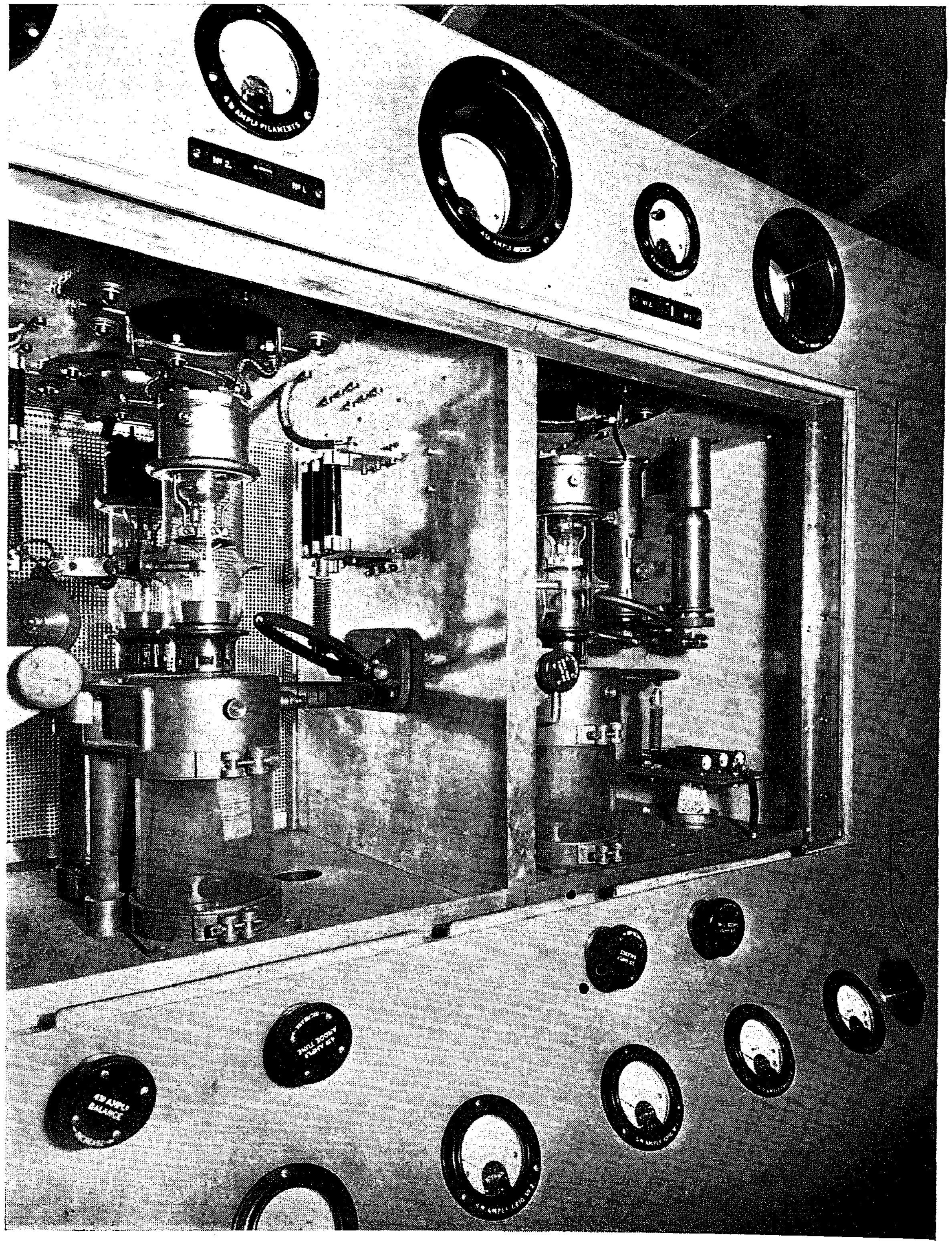

Fig. 14.—Mobile television unit: last two stages of the radio-link transmitter, showing the air-blast-cooled valves.

Plate 4

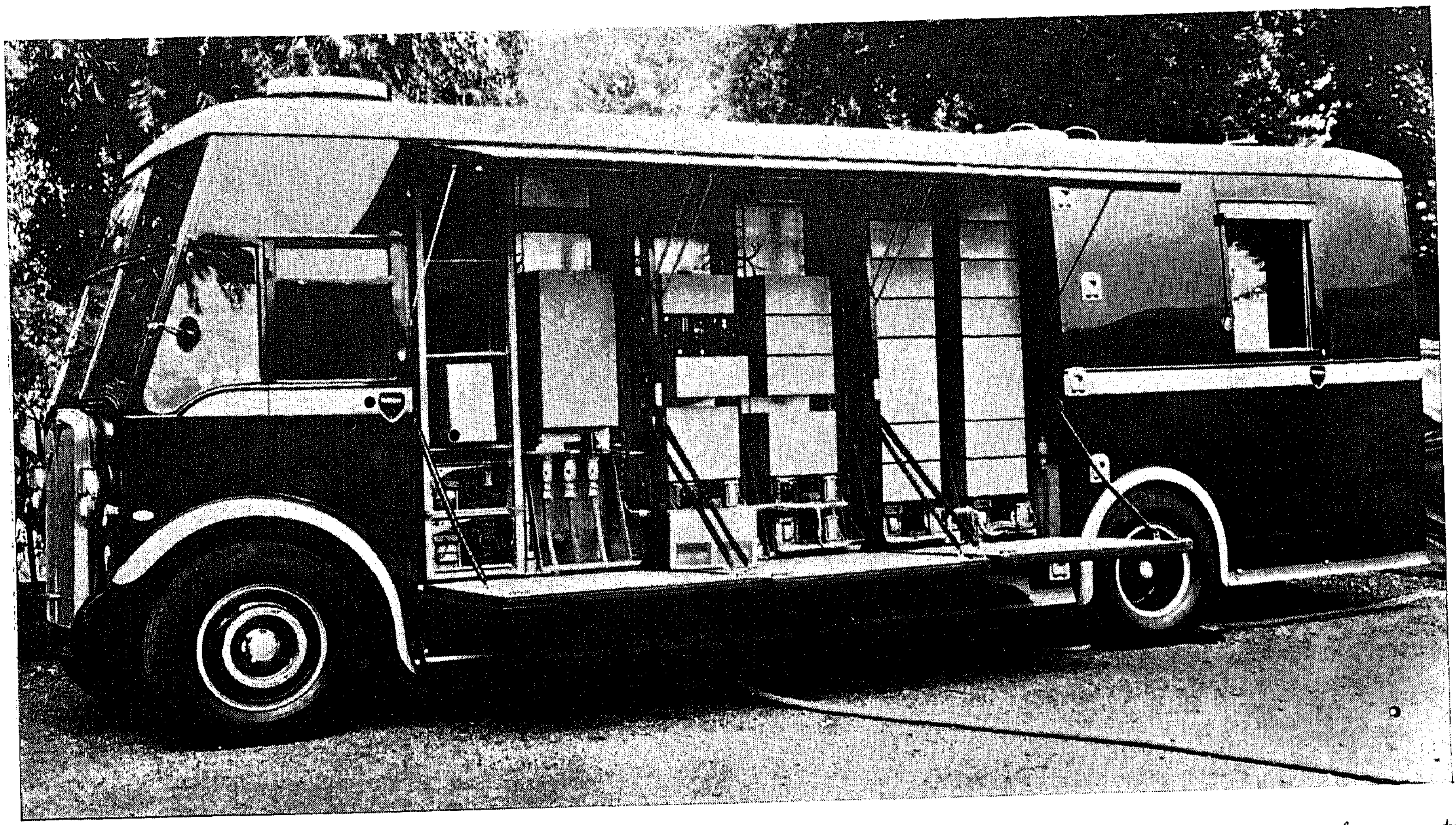

Fig. 13.—Mobile television unit: exterior of control-room vehicle with shutters opened to give access to rear of apparatus

NOTE.—The camera cables can be seen underneath the vehicle

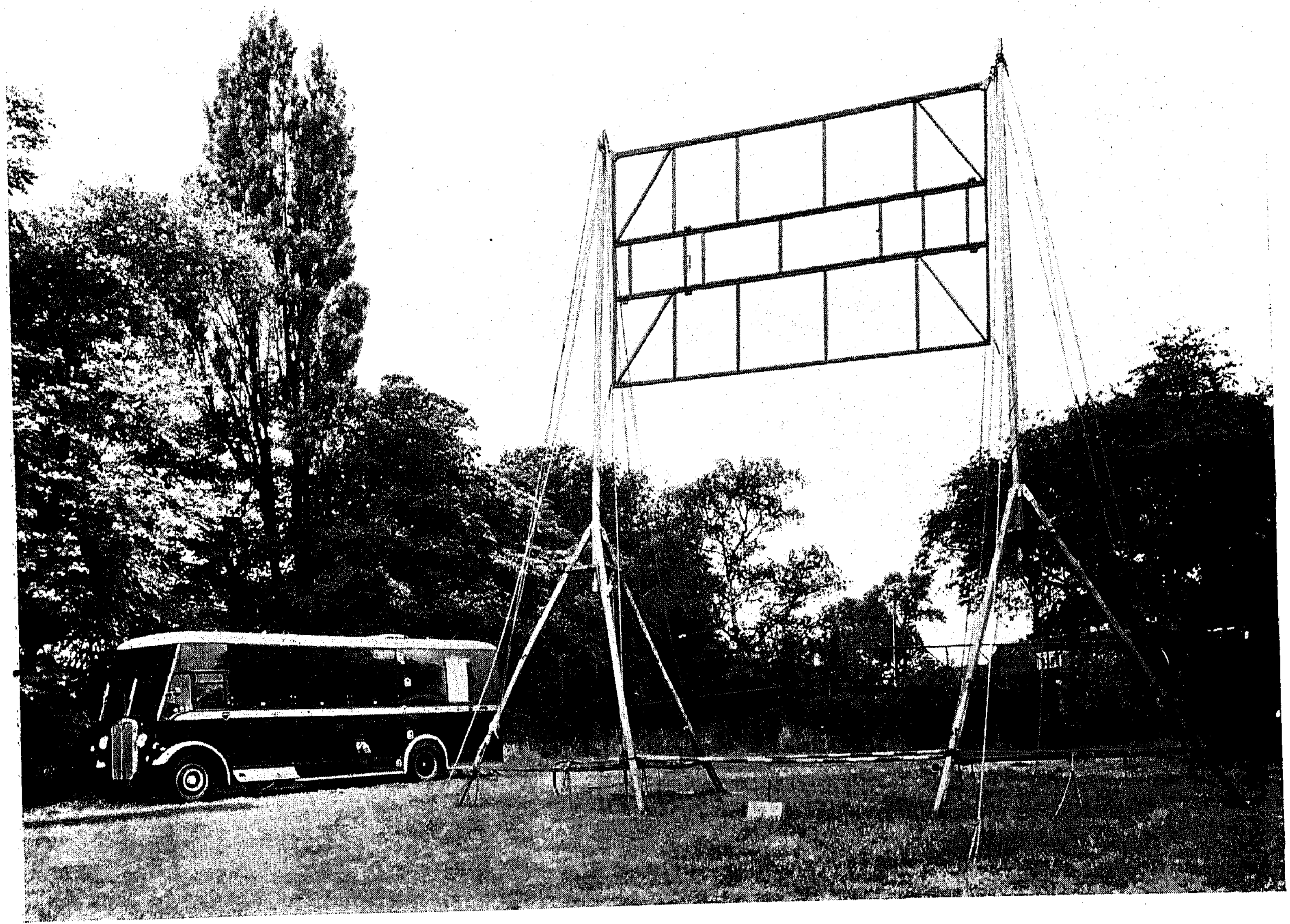

Fig. 15.—Mobile television unit: radio-link transmitter vehicle and portable directional aerial.

see and hear what is being radiated and at the same time observe the studio through the window.

It will be seen that what might be termed the programme control is carried out from the gallery, whereas the more detailed adjustment of the vision and sound circuits is carried out by a group of engineers associated with the vision and sound racks on the ground floor. A signal system is fitted between the vision mixer and these racks so that he can call for any camera to be placed on the preview channel. A system of cue lights operated by push-buttons under the control of the producer is fitted to enable him to signal announcers and the conductor of the orchestra when to commence.

In the majority of productions the various vision and sound units will be distributed in the following manner. Camera No. 1 is usually in the centre of the studio on a mobile truck which enables "tracking" shots to be done. Cameras 2 and 3 may cover the main scene from alternative view points, or they may be set for smaller side sets. Camera 4 is usually reserved for announcers and captions. The sound from the main scene is covered by means of a moving-coil microphone suspended from a microphone boom, which enables it to follow the movements of artists. The orchestra, usually situated at the near end of the studio under the window, is taken on a ribbon microphone, and there will in general be one or two other microphones at suitable points in the studio, such as the side sets. A viewing monitor is also provided in the studio, so that, for such productions as dress shows, the announcer can give a commentary while observing the picture which is actually being radiated.

(b) Marconi-E.M.I. Vision Transmitter

This is situated in a large hall on the ground floor, as illustrated in Fig. 10 (see Plate 1).

The carrier frequency is originated by a master oscillator and doubler, the master oscillator operating at half the carrier frequency, or 22·5 Mc./sec. This is then amplified by six stages of amplification in cascade. The transmitter is contained in three cubicles, of which the first comprises the master oscillator doubler and the first four stages of amplification. The second cubicle contains the fifth amplifier, which delivers some 2 kW of radio-frequency power to the grids of the sixth amplifier; this is mounted in the third cubicle.

Mixed vision and synchronizing signals from the control room, having a picture/synchronizing ratio of 1/1, are fed to the modulator by means of concentric cable, and at its input they have an overall amplitude of some 10 volts. The modulator contains effectively four stages of amplification, between the first two and the last two of which are d.c. couplings. Between the second and third stages, however, the d.c. component is lost and is subsequently restored with a very great degree of perfection. At the output of the modulator the signals have an overall amplitude of some 2 000 volts, and the picture/synchronizing ratio is unchanged at 1/1. They are then applied to the grids of the sixth amplifier, and grid modulation is effected. Owing to the nature of the modulation characteristic of the sixth or modulated amplifier, the picture/synchronizing ratio becomes modified in the course of modulation to the desired ratio of 70/30.

The H.T. supply to the modulator valves is obtained from a motor-alternator set having an a.c. output of 500 volts and 50 kW at 500 cycles. Each of the four stages has its own H.T. rectifier, which, in the case of the first three stages, incorporates hard valves, but in the case of the last stage employs a mercury-pool rectifier. For the filament heating-current for the first three stages various supplies are used, including 500-cycle and 50-cycle alternating current, and direct current obtained by rectification from the 500-cycle supply. The two valves in the last or modulator stage have individual filament-current d.c. generators, that for the last stage being insulated from earth as the filament is at high potential.

Filament current for all radio-frequency valves other than the master oscillator is obtained from a motor-generator set which has an output of 400 amperes and 24 volts. The master oscillator filament is applied separately from the mains to a transformer and metal rectifier. High-tension supplies for the output stage at 6 000 volts are obtained from a hot-cathode mercury-vapour valve rectifier, and a second supply is similarly derived at 4 500 volts and feeds the third, fourth, and fifth amplifiers. A third supply for the remaining stages is provided from a metal rectifier.

The main controls are all grouped conveniently on one control desk, from which the switching operations are effected by remote control. A sequence starting-switch is provided to prevent damage to the transmitter by the application of power supplies in the wrong sequence, and the modulator is similarly protected by a system of interlocked push-buttons. All electrical apparatus is fully protected by interlocking circuits and water-flow monitoring devices, so that in the event of a failure of any supply the transmitter is automatically shut down and cannot be restarted until the deficiency is remedied.

The provisions for the protection of personnel are such that access cannot be obtained to any of the transmitter units until all dangerous supplies have been switched off and the apparatus earthed. No supply can then be reconnected to the transmitter until the gates of all the units have been closed and locked.

In the centre of the control desk is mounted a cathode-ray oscillograph, including an amplifier and the necessary time-base circuits. Switching arrangements are provided which enable the wave-form of the picture and synchronizing signals to be examined at the output of each stage of the modulator unit, and also the final wave-form at the output of the modulated amplifier.

The total input power from the mains to the vision transmitter is 95 kVA and its output power is 17 kW, corresponding to "full picture white." It is customary to rate the power of television transmitters in terms of peak, since it is not possible to use the normal method of rating in terms of "carrier wave power" as in the case of a sound transmitter, because a television transmitter does not radiate a steady "carrier wave."

(c) Baird Studio Equipment

The transmission of scenes from the Baird studio was effected by two methods: the intermediate film process, which was the first to be employed, and the electron camera, which was introduced subsequently. There was in addition a further small studio 30 ft. by 12 ft. intended for announcements, talks, and other similar purposes, and from which transmissions were made by the spotlight system. In a further room film transmission was carried out by means of two sets of telecinė apparatus. Each of these various sources of programme was regarded as a separate unit, whose output was passed to the main control room adjoining the large studio.

(1) The Intermediate Film Process.

The apparatus for television by this process was housed in an additional sub-control room at the side of the main studio and separated from it by a three-sided window. The scene, illuminated by the studio lighting-equipment described elsewhere, was photographed on to 17·5-mm. film. The film immediately passed in succession through developing, first-washing, fixing, and second-washing tanks. On emerging from the final tank the film was immediately scanned while wet. To effect this the film was passed through an underwater gate upon which was projected a beam of light from a 60-ampere arc. The light, having passed through the film, fell upon a scanning disc running at 6 000 r.p.m. and containing 60 equally-spaced holes arranged on the circumference of a circle. The horizontal scanning component was thus derived from rotation of the disc, while the vertical component was automatically provided by the continuously moving film. The disc was driven by a $\frac{1}{2}$-h.p. 3-phase motor, the disc and motor being enclosed in a chamber and running in a vacuum. This was necessary in order to prevent weaving of the disc due to air resistance, and also to avoid dust entering the small scanning holes. The motor required a supply of alternating current at 100 cycles per sec., which was generated by a separate motor-generator. The latter consisted of three machines in tandem: the 100-cycle alternator, a d.c. motor by means of which the generator and the scanning disc could be slowly run up together, and an a.c. motor which was cut in when the unit was up to speed, thus locking the set in synchronism with the mains.

The light from the scanning disc was arranged to influence a photo-electric cell of the multiplier type, the output of which was passed to a series of amplifiers and thence to the central control room. The line-synchronizing signals were simultaneously generated by the same disc by means of a further series of 60 apertures arranged on a circle within that containing the scanning apertures. These were illuminated by a slit of light, and a photocell situated behind the disc translated these light impulses into synchronizing signals of proper shape. They were then raised in level by an amplifier and passed to the central control room.

The time elapsing between the action in the studio and its appearance on the receiving screen, that is to say, the time required to process and scan the film, was 65 sec. It was, of course, necessary to apply a corresponding delay to the sound, and to effect this it was also recorded on the film by a recording head interposed between the camera and the developer tank. A corresponding reproducing head was fitted into which the film passed after having been scanned in the underwater gate. The film was finally reeled while wet and subsequently transferred to a large drying drum.

A picture monitor was provided in the sub-control room.

(2) Electron Camera.

The studio was equipped with two experimental electron cameras whose associated apparatus was housed in a further adjacently situated sub-control room. These electron cameras were of the type in which a phalanx of electrons emitted from a light-energized photo-cathode was bodily displaced, in the motions of frame and line scan, over an electrode having at its centre a small opening which constituted the scanning aperture. One of the cameras was mounted on a movable run truck, and the other on a tripod. The scanning currents and other supplies for these cameras were all generated in the sub-control room and sent to each camera by a composite cable. The camera outputs were amplified in head amplifiers, and the output passed back along a composite cable to the sub-control room. Inter-camera fading was carried out in this control room, and the single output passed to the central control room.

(3) The Spotlight Studio.

As its name implies, transmissions from this studio employed the spotlight system, in which the artist is kept in almost complete darkness and a spot of light of elemental size is distributed over him by means of a scanning device, the reflected light being picked up by photocells.

A disc scanner was used, running at 6 000 r.p.m. and having four spirals, each of 60 holes. Each spiral was brought into action in turn by means of a further shutter disc revolving at 1 500 r.p.m. The large disc, which was as usual enclosed in an evacuated chamber, was rotated by means of a $\frac{1}{2}$-h.p. 100-cycle 3-phase synchronous motor, deriving its power from a similar motor-generator unit to that described in connection with the intermediate film apparatus. The small disc was driven by a 1/20 h.p. 50-cycle 3-phase motor taking its power from the mains. The light source was a large arc consuming 120 amperes. Owing to the intense heat generated by an arc of this power, the scanning gate was water-cooled.

The reflected light was picked up by four large photocells of the multiplier type, whose positions in the studio were adjustable in order to obtain the correct lighting effects. The outputs of these were applied to an amplifier situated at the side of the studio, whose output was passed to the central control room.

A picture monitor was provided in the spotlight projection room.

(4) The Telecinė Equipment.

Two identical sets of telecinė equipment were installed. The film was driven under continuous motion by a modified standard film projector, and after illumination by a 60-ampere arc was scanned by a disc unit identical with that already described in the case of the intermediate film apparatus. The light from the disc was picked up by a lens system, and influenced a photocell, again of the multiplier type, whose output was fed to a series of amplifiers. The output from each set of telecinė apparatus was then fed to a common control amplifier which was provided with arrangements whereby a rapid change-over of both vision and sound could be made from one projector to the other. The output was then passed to the central control room. Individual picture monitors were provided for each machine.

(5) The Central Control Room.

The various vision and line-synchronizing inputs from the several sources were first passed to individual termination amplifiers in the central control room. From these they were fed to the main vision control desk, which contained arrangements for changing from one source to another and for monitoring the wave-form.

After further amplification the vision-synchronizing signals were passed to the transmitter via a concentric cable. Frame-synchronizing impulses were generated by apparatus which was common to all of the individual programme sources, comprising a disc rotated at 1 500 r.p.m. and containing one hole which was interposed as usual between a light source and a photocell. The necessary arrangements for mutually adjusting the phase of the various scanners and the central frame-synchronizing signal generator were provided. The frame- and line-synchronizing signals were mixed in an amplifier and passed to further synchronizing amplifiers, the output of which was fed to the transmitter via a further concentric cable.

(6) Sound Equipment.

The sound from the main studio was picked up by three condenser microphones. Associated with these were a control desk and a series of amplifiers in a sound sub-control room situated above the intermediate film sub-control room at the side of the studio. If the intermediate film process was being used, the sound, having been carefully controlled as regards volume, was passed in turn through a recording amplifier, the intermediate film apparatus, and a reproducing amplifier, and thence to the central control room. When the electron camera was used, the sound output was sent, of course, direct to the central control room.

The spotlight studio was also provided with a condenser microphone and its individual amplifying equipment. These two outputs, together with those from the sound heads of the telecine apparatus, were selected as required from a sound-control desk adjacent to the vision-control desk in the central control room, at which position the main volume to the transmitter was also controlled. The signals then passed through further amplification, and were fed to the transmitter or to a monitoring loud-speaker as required.

The various vision sources were all connected to the central control room by the usual system of cue lights and interconnecting telephones.

(7) Power Supplies.

In the case of the vision apparatus, each stage of amplification had its own individual source of anode voltage, this taking the form of a mains rectifier. The filaments were heated by alternating current via transformers.

The sound-equipment H.T. supplies were derived in the normal manner from rectifiers, and the filaments again were heated from alternating current. The power supply for the arcs of the intermediate film and the two sets of telecine apparatus were derived from three d.c. generators, each delivering 60 amperes at 110 volts. The power supply for the spotlight arc was derived from a further d.c. generator delivering 200 amperes at 110 volts. All these generators were situated in the transmitter hall.

(d) Baird Vision Transmitter

The Baird transmitter was housed in a hall on the ground floor beneath the Baird studio.

It consisted of five main units: (1) the master oscillator; (2) the intermediate amplifier; (3) the final amplifier; (4) the conditioner; (5) the synchronizing modulator; (6) the vision modulator; (7) the power supplies; and (8) the evacuation and water systems.

It is a feature of this transmitter that the picture and synchronizing signals are never mixed at vision frequency and each modulates a separate part of the radio-frequency chain. The synchronizing signals are applied to the intermediate amplifier, the output of which is raised in level at the final amplifier, and also modulated by the vision signals.

(1) The Master Oscillator.

The radio-frequency signal was originated at a frequency of 1·406 Mc./sec. by means of a crystal master oscillator which was temperature-controlled in an inner and an outer oven. This frequency was then applied to a number of multipliers and amplifiers in cascade, and the unit finally delivered 100 watts at the desired carrier frequency of 45 Mc./sec. It had its own mains-derived power supply.

(2) The Intermediate Amplifier.

This contained a pair of Metropolitan-Vickers demountable tetrodes, either of which could be associated by means of a change-over switch with a set of common radio-frequency circuits, the other tetrode at any time being held as a spare. The intermediate amplifier received the output from the master oscillator and raised it to a level of 1·2 kW at black level. Grid modulation of this amplifier by the synchronizing signals was effected by application of the output of the synchronizing modulator to the control grid of the demountable valve.

(3) The Final Amplifier.

This unit was of similar design to the intermediate amplifier. The final amplifier received the output of the intermediate amplifier and raised it to a level of 17 kW under white-picture conditions. It also received the output of the picture modulator, and grid modulation was again effected at the control grid.

(4) The Conditioner.

This unit was provided to carry out certain necessary conditioning of the demountable valves before they are once more put into service after having been taken down for repair. The process of conditioning consists in applying first of all to the control grid, then to the control and screen grids, and finally to the anode as well, alternating voltages capable of fine regulation. It was in this way possible to drive off the last traces of occluded gas, the presence of which, without this precaution, would lead to the prevalence of frequent overloads upon the valves being returned to service.

(5) The Synchronizing Modulator.

This unit consisted of a 4-stage vision-frequency amplifier delivering a synchronous amplitude of 700 volts to the intermediate amplifier.

(6) The Vision Modulator.

This was a 7-stage vision-frequency amplifier receiving its input from the control room, and delivering picture signals of 1 000 volts amplitude between black and white to the final amplifier.

(7) Power Supplies.

The filament supplies for the final and intermediate amplifiers were each obtained from motor-generators delivering 200 amperes at 25 volts. The anode and screen supplies for the intermediate amplifier were obtained from a motor-generator delivering 14 kW at 7 000 volts for the anode, and 4 kW at 2 000 volts for the screen. The anode and screen supplies of the final amplifier were obtained from a motor-generator delivering 40 kW at 10 000 volts for the anode, and 2 kW at 2 000 volts for the screen. The anode voltage was in this case obtained from two machines connected in series but driven in tandem by a single motor. The modulator power supplies were obtained from rectifiers, and there was, in addition, a floating 2 800-volt 10-ampere-hour battery.

The control of the transmitter, as distinct from the modulator, was centralized at a control desk, on which was mounted an oscillograph for examining the radiated wave-form. Behind this was situated an additional panel for the centralized control of the modulators.

(8) Evacuation and Water Systems.

With each of the demountable valves was associated an evacuation system consisting of two oil condensation pumps in cascade and a rotary pump. This apparatus was entirely automatic, and created and maintained without attention an adequate vacuum in each of the valves. A complete water system was provided for cooling the anodes and heads of the valves and also the oil pumps. These were fully protected by water-flow relays, which would open the appropriate circuits in the event of a water failure.

As usual, complete protection was provided in all the apparatus so that personnel could not have access to dangerous voltages.

(e) Marconi Sound Transmitter

The transmission of sound from either of the two television systems is effected by means of one sound transmitter, which can be fed with the outputs from the control rooms of either system. This is situated on the ground floor of the Palace in a hall between the two vision transmitters, and is illustrated in Fig. 11 (see Plate 1). It normally operates upon a frequency of 41·5 Mc./sec., but is capable of working over a band of frequencies from 35 to 50 Mc./sec. It has an output power of 3 kW at 90 % peak modulation. The total input power from the mains is 78 kVA.

The transmitter is built in four separate units, each unit being housed in a metal cubicle. The carrier frequency is originated by a master oscillator and doubler, the master oscillator working at twice the carrier frequency and ensuring a stability of ± 1 part in 100 000. This is followed by five high-frequency amplifying stages. The master-oscillator doubler and the first four stages are all contained in one cubicle. A separate cubicle houses the fifth amplifier, at the anodes of which modulation is effected. A third cubicle houses a 3-stage modulator of conventional type. In the final high-frequency stage two C.A.T.9 water-cooled valves in push-pull are used, and in the main modulator stage three C.A.M.3 valves in parallel. The transmitter is designed to give high-quality sound reproduction, and enables advantage to be taken of the greater frequency band available at this short wavelength. The frequency response is flat to within 2 db. between 30 and 10 000 cycles per sec., and, in addition, the distortion factor of this transmitter is very low, the total harmonic content in the output low-frequency signal, expressed as an r.m.s. voltage sum, being 2 % at 90 % modulation.

All the valve filaments except that of the master oscillator are heated by direct current from a motor-generator having an output of 500 amperes at 24 volts. The master oscillator has its own supply from a rectifier.

The main H.T. supply at 6 000 volts (d.c.) for the fourth and fifth amplifiers and the modulator is obtained from a hot-cathode mercury-vapour-type rectifier associated with a transformer and induction regulator and appropriate smoothing circuits. Other auxiliary H.T. and grid-bias supplies are obtained from metal rectifiers. The whole of the H.T. and grid-bias supply equipment is housed in the fourth transmitter cubicle.

A control table is provided at which the essential operating controls are grouped, and the transmitter can be entirely controlled by one operator. The application of power supplies in the correct order is ensured by sequence starting arrangements, and a complete system of interlocks is installed for the protection of the apparatus and of personnel.

In an adjoining room are the necessary water pumps and air blowers for valve cooling.

(f) Mast and Aerial System, and Feeding Arrangements

As previously stated, the transmitting mast is 300 ft. in height, and the ground itself is 306 ft. above sea-level, so that the total height of the mast is 606 ft. above sea-level.

Its design is intimately connected with that of the aerials themselves. Since two separate radiating systems are required, mechanical and electrical considerations both preclude the use of vertical dipoles situated one above the other. It was necessary in order to get uniform radiation in all directions to provide for each radiating system a number of aerials uniformly spaced around the mast. To facilitate this aerial design, therefore, the upper part of the mast structure which carries the aerials has been made octagonal in section and uniform in diameter. The height of this section is 97 ft. Below this the mast consists of a more orthodox tapering 4-sided structure having a height of 118 ft. 6 in. and base dimensions of 30 ft. by 30 ft. Each of the four corners of the base girders has been taken down through the structure of the building to within a few feet of the ground to obtain a secure anchorage.

The vision signals are radiated from the upper of the two aerial systems. This consists of eight push-pull end-fed dipoles uniformly spaced round the mast. Behind them are eight energized dipole reflectors. Each dipole consists of three wires situated at the corners of a triangle having a 15-in. base, in order to simulate a dipole of considerably greater diameter than that of a wire. All the eight aerial/reflector systems are joined in parallel. A number of concentric networks are provided in order to carry out the necessary transformations, which include rendering the aerial system asymmetrical so that it can be fed by the main feeder, which is of the concentric type, matching the impedance and maintaining a constant impedance over the required radio-frequency band width. In this connection it should be mentioned that the impedance is substantially constant over a band width of 2 Mc./sec. on either side of the carrier. The main feeder has a characteristic impedance of 78·5 ohms and is 5 in. in diameter. Electrical compensation is introduced at intervals in order to minimize the existence of reflected energy.

The sound aerials are situated underneath the vision aerials, and are substantially similar, differing only in their dimensions and in the absence of the elaborate networks necessary to accommodate the wide band-width occupied by the vision signals. They are connected to the transmitter by a feeder identical with that provided for the vision system.

PART 5

OUTSIDE BROADCASTS

(a) Programme Requirements

The televising of national ceremonies and open-air events of sporting and topical interest is perhaps one of the most useful functions which a television service can fulfil. Such events can be divided into two general classes:—

(*a*) Events which can be brought within close proximity to the television station proper but not actually into the studio itself.

(*b*) Events which by their very nature occur at some point remote from the transmitter.

The events classed under (*a*) are such things as demonstrations of horsemanship or golf, and displays of physical culture. These obviously cannot be done in the confines of a studio, but it can be arranged that they take place within a selected area close to the actual television site. Such events are classed as local outside broadcasts, and their televising can be accomplished by an extension of the internal studio facilities. That is to say, cameras can be taken to the scene of operation and directly connected back to the Alexandra Palace control room by means of a length of normal camera cable. In general it may be said that the maximum allowable length of camera cable which can be used without running into serious technical difficulties is approximately 1 000 ft.

Suitable provisions exist at the Alexandra Palace to facilitate such local outside broadcasts. Special cable ducts have been laid under the road flanking the B.B.C. premises, and camera cable can be run to any point in the grounds of the Palace within the limits of 1 000 ft. from the control room.

Similar provisions exist for the direct connection of sound equipment for picking up the sound accompanying the action being televised. Exactly similar technique to that adopted in the studios themselves is thus used for local outside broadcasts, with the exception that artificial lighting is in general unnecessary.

The events classed under (*b*) include such national occasions as a Coronation procession, the Wimbledon tennis tournaments, and the Armistice ceremony. Such events occur at places remote from the main station and it is therefore necessary to employ a different technique from that employed for local outside broadcasts.

In order that events of this type may be included in the television field a mobile television unit has been formed which in effect provides the same facilities for vision and sound as are available at the main station at Alexandra Palace, although of necessity somewhat limited in scope.

The function of this unit is to form a link between the remote outside-broadcast point and the main transmitter, and its requirements are that it shall be capable of conveying both vision and sound back to the main transmitter from any point within a given operating radius.

Every effort has been made to construct the mobile unit in the most transportable form possible, so that the minimum of time is required for moving it to site and setting it to work Rapid mobility is felt to be an essential of a unit of this type, as lacking this quality much of the topicality of the outside-broadcast transmissions will be inevitably lost, and their value thereby greatly reduced.

At present, setting up the equipment for an outside broadcast takes a comparatively long time, perhaps a day or even longer. This is considered to be far too long, and every effort is being made to arrive at a design of all equipment including the smallest accessories such that the process of setting up for transmission can be accomplished in an hour or even less.

Such an achievement clearly involves many difficulties, but it is considered that until it is possible to effect the setting-up in a time of this order, complete flexibility will not have been reached.

(b) Travelling-Studio Equipment

The travelling control room, which, as has been stated, is brought into use in cases where it is required to televise events taking place at points remote from Alexandra Palace, consists of a large motor vehicle, 27 ft. 6 in. long, 7 ft. 6 in. wide, and 10 ft. 8 in. in height, fitted with a closed body of special design.

Inside the vehicle body is mounted all the apparatus required to operate three Emitron cameras and six microphones. The cameras, which when the vehicle is in motion are carried in specially sprung cradles to protect the fragile tubes from the effect of road shocks, are in all respects similar to those used for studio purposes.

When the vehicle reaches the site of the broadcast the cameras are taken out to appropriate positions, being connected to the apparatus by multi-core cables similar to those used in the studio and each of a total length of 1 000 ft.

Provision is made on the vehicle for carrying 600 ft. of this cable on drums which are lowered through the rear doors of the body by means of a winch mechanism which enables them to be deposited on a hand-truck and so easily transported to the required point. After use, the drums are raised into the vehicle by reversing the operation of the winch.

The apparatus contained in the vehicle consists of all essential portions of the control-room scanning and amplifying equipment described in Part 4(a) of the paper, and includes duplicate sets of pulse-generating equipment either of which can be brought into action in the event of failure of the other.

Provision is made for fading from any one camera to another, or for the superimposition of the outputs from two or all three cameras. Two cathode-ray vision monitors are provided, one for the purpose of viewing the transmission actually taking place, and the other for previewing the picture emanating from the camera to which it is next proposed to fade.

The outputs of the six microphones are connected to a six-way fading mixer, so that any microphone or combination of microphones may be chosen as dictated by the requirements of the programme being transmitted. Duplicate speech amplifiers are provided and are equipped with a logarithmic volume indicator and a monitoring loud-speaker. The speech amplifiers are designed to deliver to a Post Office land line a signal of appropriate level for transmission to Alexandra Palace.

The whole of the equipment is made up in the form of flat-fronted panel units mounted in 7-ft. racks which extend down both sides of the body, with a central gangway for the operating personnel, as shown in Fig. 12 (see Plate 3).

The racks themselves are securely bolted together at the top and bottom and at several intermediate points, and the foot-plates of each set are bolted securely to a rigid frame which, in turn, is supported through the medium of resilient indiarubber insulated bushings, upon a series of transverse bearers carried by the chassis frame.

The two sets of racks are linked across the top at four points by strong tubular members heavily braced in two planes by means of welded radius plates.

The whole of the rackwork thus comprises a very rigid structure, carried on rubber-insulated mountings and entirely unconnected with the bodywork of the vehicle, and in consequence of its mass and the method of mounting it is not susceptible to the effect of road shocks.

In practice this method of construction has proved highly successful, and a minimum number of faults due to the disturbance of the equipment by vibration have occurred.

The rear of the racks is not accessible from the interior of the body, and to overcome the resultant difficulty of access to apparatus a particular form of body construction has been adopted, as illustrated in Fig. 13 (see Plate 4). The sides of the body have been made to open over the greater part of the length in the form of flaps. The top half of the bodywork is formed of flaps opening upwards and the lower half of flaps opening downwards. The lower flaps are retained in the horizontal position by means of chains, and they form platforms on which those manipulating the apparatus from the rear may stand at a convenient height. The upper flaps are supported by rods engaging in sockets in the bodywork and serve as a roof to ward off falling rain.

All the equipment is mains-operated, consuming a total of about 5 kW, and is adopted to operate from either single-phase or 3-phase 50-cycle supply mains over the range of voltages normally encountered.

In the absence of supply mains the mobile control room unit may be operated from a petrol-driven generator, details of which are given in the succeeding Section.

The chassis is of the 4-wheel 45-h.p. 6-cylinder petrol-driven type, and in the fully loaded condition weighs approximately 9 tons.

(c) Travelling Vision-Transmitter and Power Unit

The preceding Section described the mobile control-room apparatus for generating and monitoring vision and sound at an outside-broadcast point remote from Alexandra Palace. Both sound and vision must clearly be conveyed to Alexandra Palace in some manner so that they may be broadcast from the normal aerials to be received in the ordinary manner on viewers' receiving sets.

Conveying the sound signals to Alexandra Palace presents no difficulties, as use can be made of Post Office line circuits in the usual manner, but the vision signals present a serious problem. At the present moment it is not possible successfully to transmit television signals through the medium of ordinary land-line circuits of appreciable length, and while special television circuits exist, as will be described in a later section, their scope is limited at present, and many events of interest take place in localities far removed from these special circuits.

In circumstances such as these, other means for linking the mobile control room with Alexandra Palace must be adopted, and to this end a second mobile unit comprising an ultra-short-wave radio transmitter has been constructed.

This unit is mounted in a second vehicle of precisely similar construction to that used for the mobile control room, as previously described.

The transmitter is built into two sheet-steel cubicles, which are disposed either side of the centre line of the vehicle body and are carried by means of resilient bushings upon transverse bearers affixed to the main chassis members of the vehicle.

The transmitter is designed to operate at a frequency in the region of 64 Mc./sec. and delivers to the aerial a power of 1 000 watts at peak picture-white modulation.

The radio-frequency portion of the installation consists of a valve master oscillator operating at 32 Mc./sec., having a frequency stability of 1 part in 5 000. This is followed by one doubler stage, and five stages of neutralized push-pull radio-frequency amplification, modulation being by grid control on the final stage, depicted in Fig. 14 (see Plate 3).

All valves are of the air-cooled type throughout, and in the case of the final and penultimate stages consist of small water-cooled valves designed for working at these frequencies, modified for air cooling by having intimately affixed to their anodes a type of copper honeycomb, through the cells of which air is rapidly forced. Heat generated by the dissipation of energy in the valves is thus removed, without the use of cooling water, the presence of which would be inconvenient in a mobile vehicle.

The modulating equipment is designed on the same lines as that installed as part of the Alexandra Palace vision transmitter, but of course on a reduced scale, air-cooled valves being used throughout. The whole equipment is designed to pass, with a minimum of loss at the high frequencies, the wide frequency band required, and to transmit a signal having the same general form as that radiated from the main vision transmitter.

The output of the transmitter is adapted to feed the aerial either through a balanced open-wire feeder of about 500 ohms characteristic impedance, or, alternatively, by means of a coaxial high-frequency cable of 110 ohms characteristic impedance.

The first type of aerial used consisted of a two-stacked balanced series phase array adapted to emit a vertically polarized wave and having marked directional properties. This aerial was constructed on a Jarrahwood frame, approximately 18 ft. long by 12 ft. high, which was slung between two 30-ft. transportable wooden masts with tripod bases, both the masts and the aerial frame being capable of being dismantled into component parts of such size as to make transport possible. The vehicle and masts, as set up at the All-England Tennis Club at Wimbledon, are shown in Fig. 15 (see Plate 4).

It will be noted that in the interests of portability the height of the transmitting aerial was kept low, an action which was held to be justifiable on the following grounds.

Evidence showed that good-reception conditions could be obtained using a high transmitting aerial in conjunction with a comparatively low receiving aerial, and it is generally conceded that the converse must in theory apply. Consequently it was felt that if a very high aerial could be installed at the receiving point, a comparatively low aerial could be used with the transmitter, with manifest advantages from the point of view of rapid erection and dismantling. An aerial, details of which are given in a later Section of the paper, was therefore installed at the top of the Alexandra Palace transmitting mast for purposes of reception.

It must be understood that a very limited time was available for experimental work on these aerials, as it was necessary to provide some form of equipment in order that the apparatus should be available for certain imminent outside broadcasts, notably the Coronation procession and the tennis championships at Wimbledon.

In practice, rather variable results were obtained with the low series phase aerial, as it was found that from some outside broadcast sites a good signal strength giving a satisfactory signal/noise ratio was received at Alexandra Palace, whereas from others the results were very poor. For example, from Wimbledon a field strength of approximately 2 mV/m. was obtained, whereas from Hatfield Aerodrome, whence an attempt was made to relay the start of the King's Cup Air Race, a very low signal strength of the order 250 μV per metre only was obtained, which gave an insufficiently good ratio of signal to noise to maintain synchronism of the picture. The actual length of the radio-link path was 11½ miles in the case of Wimbledon, and 13 miles in the case of Hatfield, and there clearly is not sufficient difference in these distances to account for the widely divergent field strengths obtained.

Some attempt was made to determine the factor influencing this divergence, and inspection of the topographical features of the intervening country revealed that in the case of Wimbledon, while the actual height of the site above sea-level was not great, being of the order of 100 ft., the transmitting aerial stood effectively on the summit of the highest ground in the district and a very marked falling-away of the ground occurred immediately, there being no high ground in the path of the wave for a number of miles.

In the case of the Hatfield site, on the other hand, the transmitting aerial stood on fairly level ground, there being no falling-away in the direction of the receiving point. There was in fact a certain amount of rather higher ground between the transmitter and the receiver, fairly close to the transmitting aerial, and it could only be assumed that this had the effect of introducing local attenuation, which resulted in the weak signal strength to which previous reference has been made. It would therefore appear that one of the most important influences on the performance of a short-wave transmitting station of this type with a low aerial lies in the nature of the immediately surrounding country. That is to say, if the transmitting aerial stands at the top of a local eminence with the ground falling away in the direction of the receiving point, and no high ground exists in the path of the wave for a number of miles, the signal strength obtained at the receiving point is likely to be good, even though there is some high ground between the transmitting and receiving aerials to the exclusion of the possibility of an optical path, provided that the obstruction is at some considerable distance from the transmitter. On the other hand, if an appreciable tract of ground, higher than or even level with that on which the transmitting aerial stands, exists in the vicinity of the transmitting aerial and between it and the receiver, very severe local attenuation appears to occur.

At present no quantitative data are available regarding this point, but field-strength surveys tracing the attenuation of the wave under various conditions will be made as soon as equipment for this purpose is completed.

It is well known that the height of either the transmitting or the receiving aerial has a very marked influence upon the received signal; consequently, after the difficulties experienced at Hatfield, attention was turned to the possibility of using a higher transmitting aerial in order to obtain a better ratio of signal to noise in the received signal. At the Pinewood film studios, Buckinghamshire, whence television broadcasts depicting the making of a film were carried out, it was found that raising the series phase array some 50 ft. on to the roof of the studio gave a gain of some 10 db. in the received signal compared with that obtained with the aerial at ground-level.

Practical experience to date therefore indicated that the use of a higher transmitting aerial was eminently desirable, and as the series phase array mounted on a somewhat bulky frame was clearly not a very convenient form of aerial for mounting at greater heights, attention was turned to other and simpler forms of aerial array which should be lighter in weight and more easily supported on a higher mast.

Comparisons made between the series phase array and a single vertical centre-fed dipole aerial at the same height indicated that the gain due to the former was approximately 6 db. The addition of an unfed vertical dipole reflector resulted in a gain of 2 db., so that for practical purposes it may be said that the dipole with reflector gives approximately 4 db. less signal strength than the series phase array, if erected at the same height, but owing to the very much lighter nature of the former it is possible to erect it at a greater height with a corresponding increase in received field strength. In later outside broadcasts, therefore, a single dipole radiator with reflector has been used, erected on wooden poles fastened to existing buildings at heights from 80 ft. to 100 ft. above ground-level as found to be practicable, and giving received field strengths estimated to be from 12 to 15 db. above that given by the series phase array mounted on 30-ft. masts. Owing to pressure of time it was not possible to obtain exact quantitative results in all cases.

The raising of the transmitting aerial to these greater heights has brought in its train certain difficulties concerned with the feeding of the aerial. For example, the use of long open-wire feeders is extremely inconvenient, as they are fragile and difficult to transport and are also liable to become twisted unless considerable pains are taken with their erection. Further, if they come into close proximity with metal objects, such as roofs or drain pipes, serious losses are liable to occur.

It is clear that coaxial types of feeders if sufficiently robust and flexible represent a more convenient method of feeding the aerial, provided that the loss introduced thereby is not excessive. A type of lead-covered high-frequency feeder having spaced internal insulation of low power factor, and a characteristic impedance of 110 ohms, was used for several of the later outside broadcasts and gave a very good performance from the electrical point of view, in that the losses for the length required were extremely small. This feeder, however, was originally designed for permanent installation and not for continuous handling, and when used for the purpose described it was found to be too fragile to be really practicable. In consequence a high-frequency cable has been developed of similar design but having a copper-tape armouring in place of the lead covering, and experimental lengths which have been tested show considerable promise from the point of view of both electrical suitability and mechanical strength, while being much lighter than the lead-covered type. It may therefore be said that the problem of feeding high portable aerials has been largely overcome, as the new type of feeder can be treated as a flexible cable and repeatedly wound up on a drum without damage.

The question of a suitable support for a higher aerial has received a good deal of attention, and numerous proposals have been considered. The practice of lashing wooden poles to existing buildings is clearly of the nature of a makeshift, and it occupies far too much time to be admissible in a transportable equipment where rapidity of setting up is regarded as of cardinal importance.

The use of portable masts does not offer an entirely satisfactory solution to the problem, as wooden masts of sufficient height to be effective are largely impracticable, on the grounds of the time taken for their erection and difficulties which are frequently encountered as far as space is concerned. Steel portable masts are equally inconvenient, with the added disadvantages of greater weight and the bad influence which a metal mast with its stay wires is likely to have upon the radiating properties of the aerial system.

Attention was therefore turned to the fireman's ladder, a highly specialized and well-developed form of structure which is ideally suited to the purpose in view, in that it combines extreme portability with ease and rapidity of erection.

Designs have therefore been drawn up for a lightened form of wooden extensible ladder carried on a motor chassis which will form a rigid base for the aerial mast when the latter is erected.

The ladder will be pivoted on a rigid frame at the rear of the chassis, so that when lowered it will lie along the roof of the closed body with which the vehicle will be fitted. Erection will be accomplished by means of power derived from the engine, and it is anticipated that the process of raising or lowering will occupy only 2 or 3 minutes.

The mast vehicle will also serve the dual purpose of a tender for the mobile control room and transmitter vehicles, carrying all necessary accessories such as drums of additional cable, spare parts, and the like.

Mobile Power Unit.

A third vehicle of similar construction to those containing the mobile control and transmitting apparatus houses a petrol-driven engine-generator set capable of supplying power for both the other units, thus making the mobile outside-broadcast equipment independent of supply mains in places where these are not available or are unsuitable.

The engine is of the 6-cylinder omnibus-propulsion type and develops 120 b.h.p. at 2 200 r.p.m. It is direct-coupled to a 3-phase 415-volt 50-cycle alternator operated at 1 000 r.p.m., at which speed the engine is adjusted to develop 50/55 b.h.p., giving a maximum electrical output of approximately 30 kW.

The engine and alternator are carried on a fabricated bedplate which is rigidly secured to the main members of the chassis. The engine is covered by a bonnet at the front end of which is mounted a radiator for cooling purposes, through which a fan draws air from the interior of the body. The heated air is ejected through an aperture in the floor boards of the vehicle and, in consequence, the interior of the body is well ventilated and kept free from noxious vapours.

The engine is provided with a centrifugal governor operating on the throttle valve of the carburettor, designed to give an accuracy of speed control under widely varying load conditions of $\pm 2\frac{1}{2}$ %. Under the comparatively steady-load condition representing normal working, the speed remains sensibly constant. The output voltage of the alternator is controlled by an automatic voltage regulator of the carbon-pile type, the chief function of which is to protect the apparatus against dangerous voltage surges during the process of switching load on and off.

Owing to the fact that the engine is liberally rated and thus operated well below its maximum output power and speed, commendably steady and sweet running is obtained over long periods with a minimum of attention and without vibration and trouble.

(d) Radio-Link Receiver at Alexandra Palace

The receiving aerial is mounted on the extreme top of the Alexandra Palace mast and is designed for the reception of vertically-polarized waves, taking the form of an electrically cylindrical dipole mechanically simulated by a number of wires arranged in a circle. It is connected through a series of transformations of similar form to those used on the vision aerial, to a lead-covered air-spaced paper-insulated coaxial feeder of about $\frac{3}{4}$ in. diameter, terminating at the receiver adjacent to the control room.

The receiving aerial is, of course, tuned to 64 Mc./sec. and it so happens that, as a result of transformations and the attenuation of the feeder, the signal voltage produced across the terminals of the receiver is approximately equal to the field strength of the signal incoming to the aerial.

An unwanted signal of the order of 10 volts (r.m.s.) total at the terminals of the receiver is induced into the receiving aerial from the local sound and vision aerials, and high-pass filter circuits are incorporated giving a discrimination of some 70 db. in favour of the wanted signal without the introduction of significant phase distortion.

Assuming a field strength of 2 mV/m. from the distant station, it will be seen that the wanted signal and local interference appear sensibly equal at the input to the first stage of the receiver.

The remaining discrimination between wanted and unwanted is achieved by the use of a superheterodyne receiver with a first detector having linear characteristics over a wide range, so as to preclude the possibility of cross-modulation, and intermediate-frequency stages having suitable band-pass characteristics.

The receiver takes the form of a 10-stage superheterodyne using an intermediate frequency of 7 Mc./sec. and is provided with automatic volume control and indicating instruments, including an oscilloscope for observing the received signal wave-form. No amplification is used at the original frequency (prior to the frequency changer), but three stages of vision-frequency amplification are introduced after the second detector, arrangements being made that the output shall contain the full d.c. component of the signal.

The output is thus in the usual form of vision + synchronizing signals, which is applied to the vision transmitter without the introduction of any further impulses or signals. It is taken to a suitable point in the control room, where, by means of relays, the input to the vision transmitter can be rapidly changed over from the output of the local studio apparatus to the output of the receiver. A rapid change-over is essential, as it is necessary to change from locally-generated synchronizing signals to those coming by radio from the distant point, and a complete cessation of synchronizing impulses to the transmitter would cause serious overloads if maintained for an appreciable space of time.

(e) Television Transmission over Cables

Attention in this country, as well as in others, has for some time been directed towards the transmission of television signals through line circuits, not only for the purposes of linking up outside broadcast transmission but also to permit ultimately of a simultaneous broadcast of a television programme from a number of widely-separated radio stations. A detailed examination of results so far obtained falls rather outside the scope of the paper, but it is felt that some brief reference to the broad lines along which investigations are proceeding would not be out of place.

In general, the types of circuits under consideration have fallen into three main categories:—

(*a*) Unbalanced coaxial cables designed for multi-channel telephony and/or television.
(*b*) Balanced-pair low-capacitance cables primarily designed for television.
(*c*) Normal telephone circuits.

As regards (*a*), experiments are in progress by the Post Office Engineering Department to determine the requisite conditions for satisfactory operation on a long route of cable of this type, with particular reference to the coaxial circuits already existing between London, Birmingham, and Manchester, intended for multi-channel telephony.

As regards (*b*), a network of this type of cable, supplied by the Marconi-E.M.I. Television Co. to the Post Office, has been installed round the centre of London, following the route depicted in Fig. 16. As will be seen, this route embraces numerous points of interest, including the site of many national functions as well as places of entertainment such as theatres, etc., and proceeds via Broadcasting House to Alexandra Palace. Tapping points are provided at frequent intervals along the whole cable route.

All signals originating on this circuit are led into a repeater station at Broadcasting House, where equalization and phase correction take place, after which the signals are amplified and directed to Alexandra Palace, where further equalization and amplification is necessary before they are applied to the vision transmitter.

As regards (*c*), the British Broadcasting Corporation has carried out certain experiments on short lengths of ordinary telephone circuit with the particular object of using such circuits as extensions to the balanced television cable where distances of 1 or 2 miles only are involved. The use of such spur circuits would be invaluable in cases where the site of an outside broadcast is situated a mile or so from the main television-cable route.

Preliminary investigations on these lines have been made to determine the suitability of ordinary dry-core paper-insulated cables for the transmission of frequencies in the vision range. The primary constants vary, not only with the physical dimensions of the pair concerned, but also with its disposition relative to the other conductors in the cable. The iterative impedances of pairs measured vary between 75 and 140 ohms.

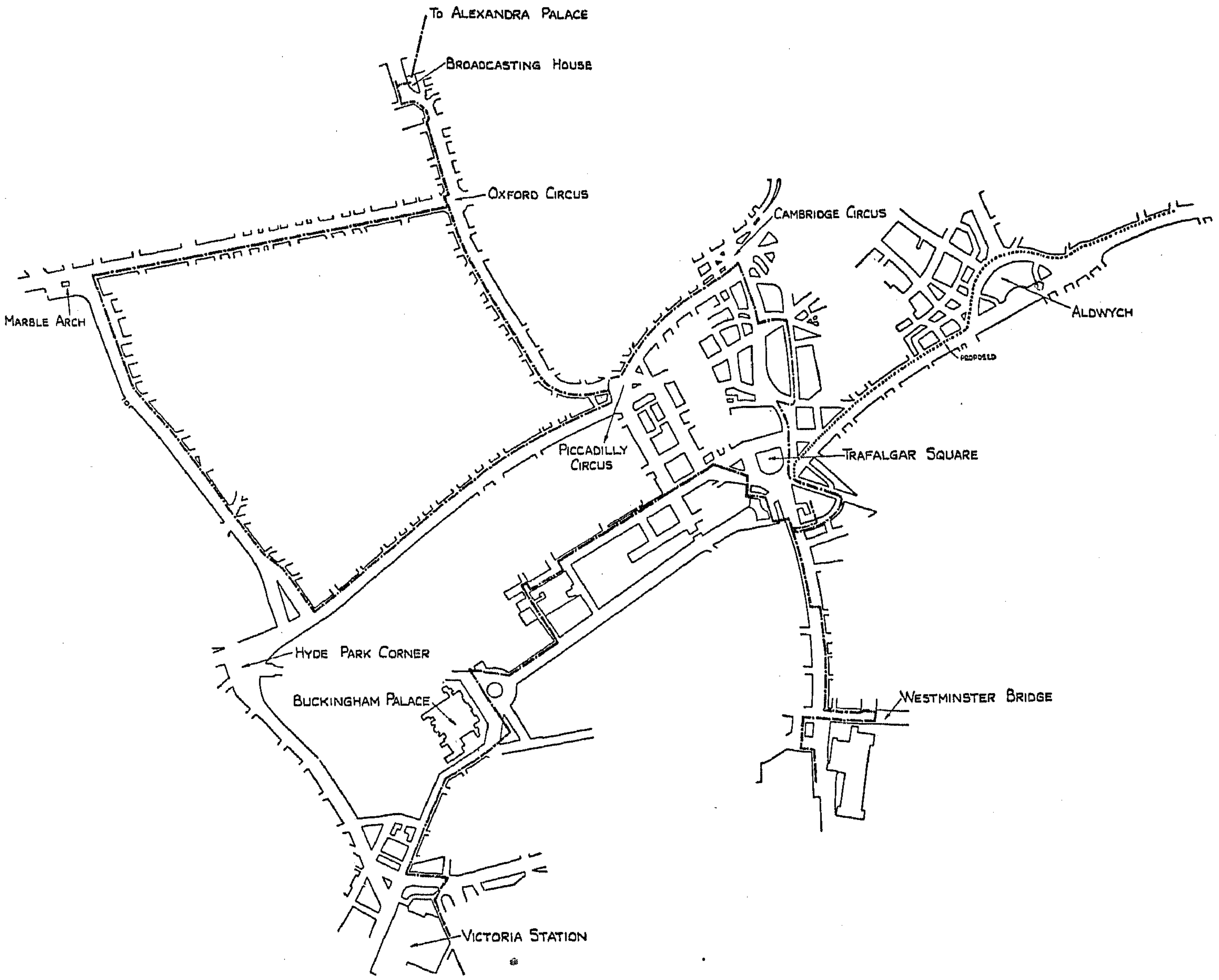

Fig. 16.—Balanced television cable route.

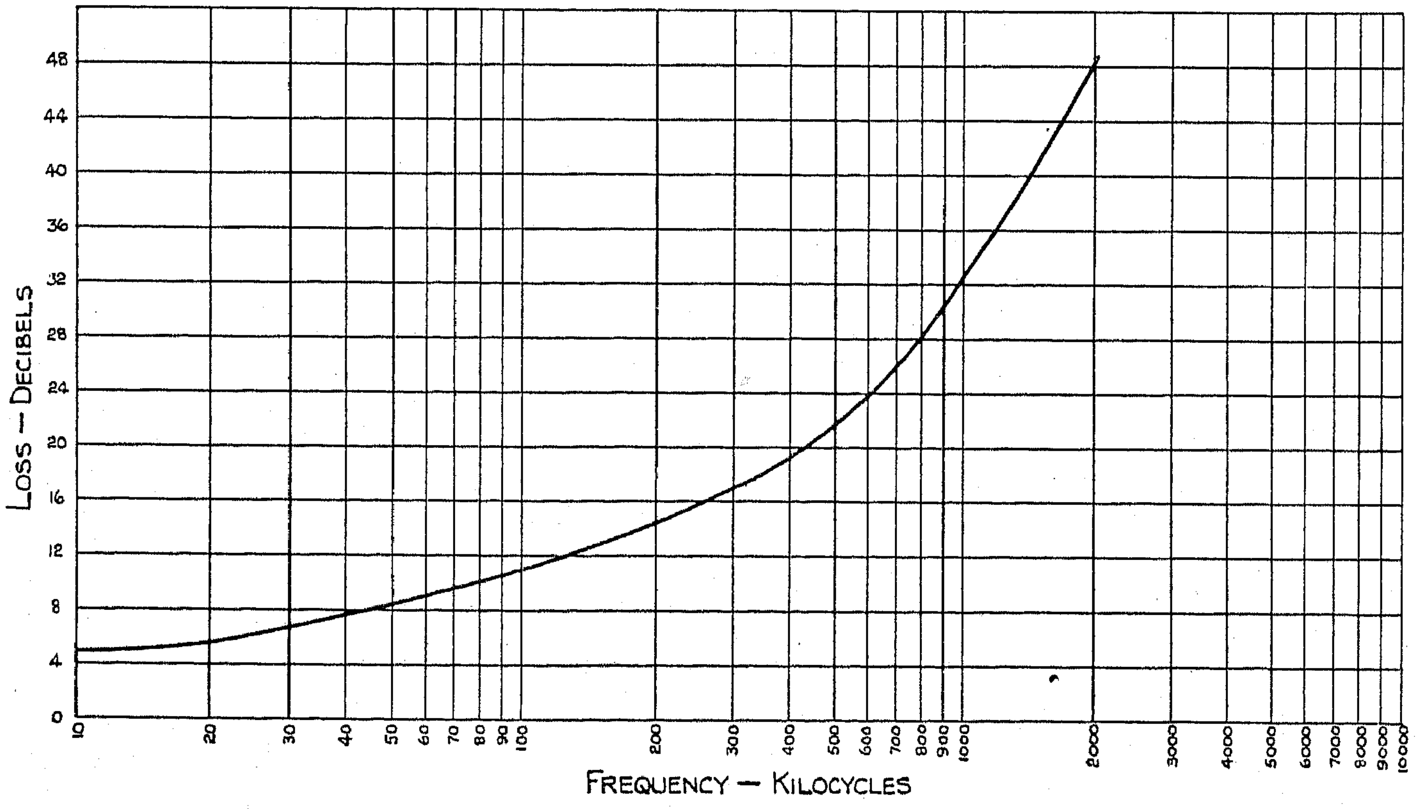

Fig. 17.—Insertion loss characteristic between 140-ohm resistances of 1·2 miles of 10-lb. paper-insulated cable.

Fig. 17 shows the insertion loss/frequency characteristic of 1·2 miles of 10-lb. twisted pair in a particular cable, measured between 140 ohms impedance. The shape of the characteristic is such that it can be equalized quite easily to within ± 1 db. over the whole frequency range by simple constant-resistance networks.

Measurements made on short lengths of cable indicate that where small-gauge conductors are concerned the high-frequency value of inductance is reached below 200 kc./sec., which means that at frequencies above this value the frequency/phase characteristic is linear, apart from a secondary effect of attenuation which becomes apparent at the higher frequencies. For the limiting lengths of circuit contemplated, it is possible to obtain the phase characteristic up to 200 kc./sec. by open-circuit and short-circuit impedance measurements. The phase distortion introduced by the attenuation-correcting networks has to be compensated, but as the required correction can be easily calculated this presents no difficulty.

A problem which requires special attention is the connection of the balanced circuit to an unbalanced amplifier at the low-level end of the circuit, as the longitudinal currents normally present in the cable pair must be much attenuated before they are effective in the unbalanced input of the amplifier. A specially-designed shielded repeating coil was included in a circuit of suitable constants, and was found to transmit frequencies in the range 50 cycles per sec. to 2·2 Mc./sec. with small attenuation and phase distortion.

With this arrangement of terminal apparatus, the noise level on the 1·2-mile section of cable referred to in Fig. 17 was better than 50 db. below the equalized signal. This method of transmission has not yet been used, and experimental work is still proceeding.

PART 6

PERFORMANCE OF THE STATION

(a) Field-Strength Measurements

A series of field-strength measurements have been taken on the television transmitters at Alexandra Palace, using for the most part the sound transmitter operating on 41·5 Mc/sec.

It has not been practicable to examine the field from the vision transmitter with the same detail as that of the sound transmitter, owing to the nature of its modulation, but comparison measurements of the relative value of field strength of the two transmitters have been made at numerous points, and it has been found that the average field strength due to the vision transmitter is 85 % of the sound-transmitter intensity.

This result is to be expected, as the vision transmitter radiated power varies from 17 kW at peak white to about 1·5 kW at black, with little radiation during synchronizing signals. The average radiated power is thus comparable with that of the sound transmitter which operates with a carrier-wave power of 3 kW.

Fig. 18 is a contour map of the field strength at ground level over the region within 25 miles of the transmitter.

The apparatus used for determination of the field strength was mounted in a vehicle, and consisted of a field-strength measuring receiver designed on the following lines.

The receiver took the form of a superheterodyne, using an intermediate frequency of 500 kc./sec., in which the input terminals were connected directly to the frequency-changer unit through an aperiodic coupling.

The efficiency of the frequency changer was shown to be independent of frequency, and consequently the received ultra-short wave signal could be measured by direct comparison with a locally generated medium-wave signal, the local-oscillator frequency being altered as required.

The efficiency of the aerial system at the required wavelength was determined by means of a loop radiator giving a calculable field, and once this had been evaluated it remained unchanged, provided that the operating wavelength was not altered.

In operation the receiver was set up and adjusted for the incoming ultra-short-wave signal, and the deflection produced by it on a galvanometer was noted. The medium-wave local-signal generator was then switched on and the frequency of the receiver local oscillator adjusted to an appropriate value. The voltage injected by the local-signal generator was then adjusted until the same reading on the galvanometer was obtained, and the voltage so injected determined by means of a thermal milliameter and calibrated attenuator. The value of voltage so obtained was then equal to the voltage due to the distant ultra-short-wave signal, and by applying a suitable factor (previously determined) for the aerial system, the actual field strength of the distant signal could be evaluated.

(b) Propagation over Long Distances

Field-strength measurements have been made at distances from 50 to 800 km. in an approximately straight line in a northerly direction to determine the behaviour of ultra-short-wave signals beyond the normal service area.

Fig. 19 shows the results, plotted in terms of *Ed* against distance, for day and night conditions.

It will be noted that these results appear to establish quite clearly the existence of a weak sky-wave at distances beyond about 150 km. under both day and night conditions, and this fact will have to be taken into account from the interference point of view in the consideration of the establishment of further stations.

(c) Reports of Reception, and Interference Problems

Reports of reception of the Alexandra Palace television transmissions have in general been encouraging.

The range of the station was originally estimated to be approximately 25 miles, but in practice it has proved to be better than the value forecast, in that it is fairly safe to say that good reception can be obtained up to about 35 miles, except in cases where exceptionally bad interference is encountered.

Reports of vision reception have been received from places as far distant as Brighton, Southend, Cambridge, and Bedford, which are situated at distances of from 40 to 60 miles from the Alexandra Palace. Reception in these cases has been carried out under exceptionally favourable conditions, such as the receiving station being situated on high ground and some distance from sources of interference; consequently, these results cannot be regarded as entirely normal.

Reports of reception from even greater distances have been obtained, including such places as Rugby, which is approximately 70 miles from Alexandra Palace, and even from a place in the vicinity of Manchester which is situated about 190 miles from Alexandra Palace.

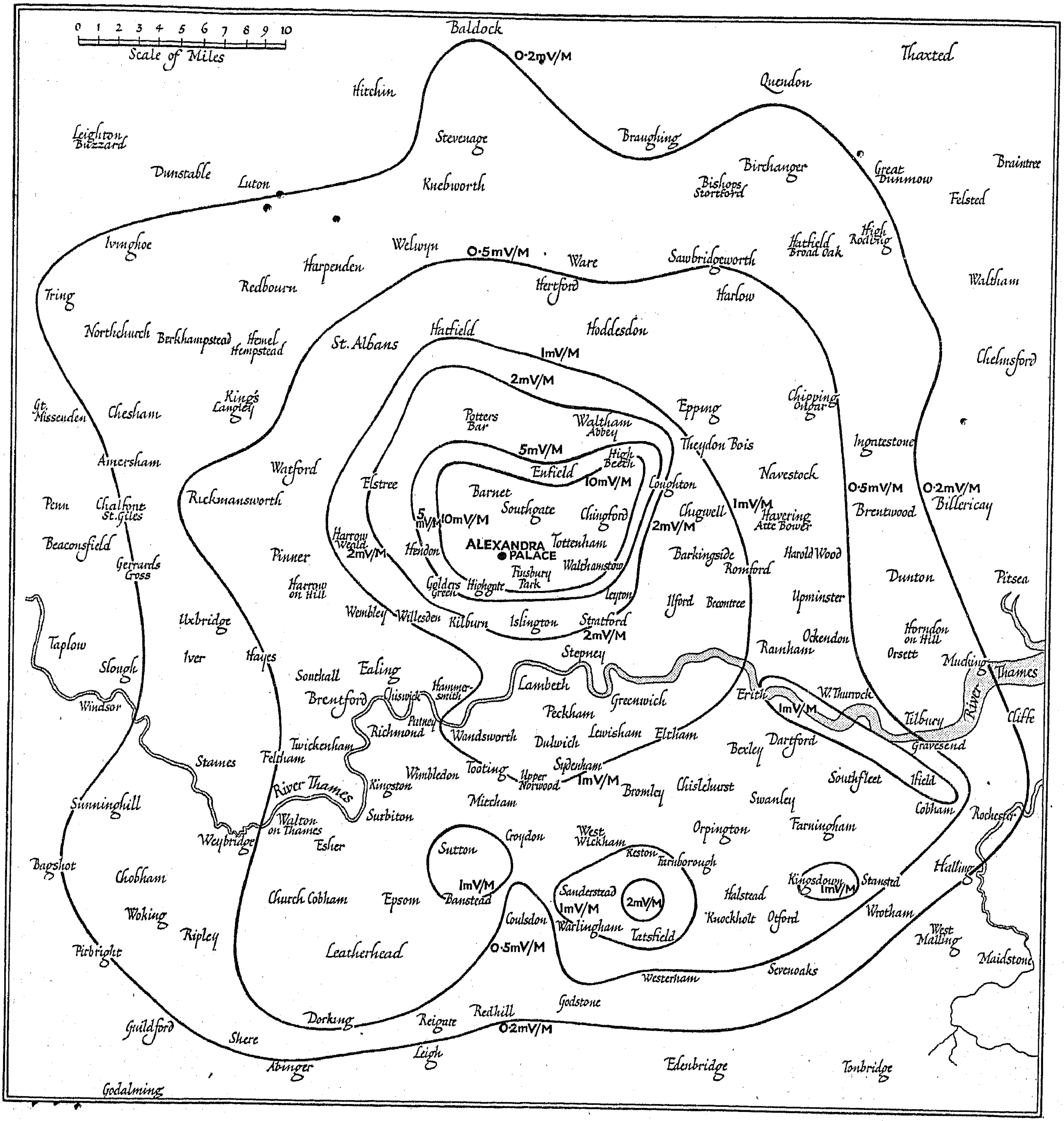

Fig. 18.—Field-strength map of London Television Station.

In the case of the former, reception conditions were quite exceptional, the receiver being situated at the top of a 110-ft. concrete water tower standing in the middle of fields at a considerable distance from all roads. In the latter case it must be assumed that reception was due to reflection phenomena.

The whole question of distant reception is, as usual, bound up with conditions of interference, and there seems little doubt that the limiting condition for reception lies in the ratio between the signal and the noise due to sources of interference extraneous to the receiver. It appears that in normal circumstances the condition is not reached where valve and other noises in the receiver itself introduced by the use of excessive gain form a limiting factor. It has been found that on the ultra-short wavelengths used for television the most serious forms of interference are due to two main causes. First there is the interference due to electro-medical apparatus used for high-frequency diathermy, of which two types are in general adopted. These may be generically described as "spark diathermy" and "valve diathermy."

The former usually consists of a multiple spark-gap supplied with alternating current at high voltage by means of a transformer operated from the supply mains. Associated with the spark-gap is a crude oscillatory circuit having much the same form as that used in early spark transmitting apparatus. Electrodes directly tapped across a part of this circuit are applied to the patient, and currents of the order of some amperes induced into the part under treatment, on wavelengths of from 3 to 10 metres, the actual wavelength being under the control of the operator. Such a machine radiates damped waves having a large band width and possessing great potentialities for interference, which, however, appears to be limited to a comparatively small range, as the radiated wave seems to be rapidly attenuated.

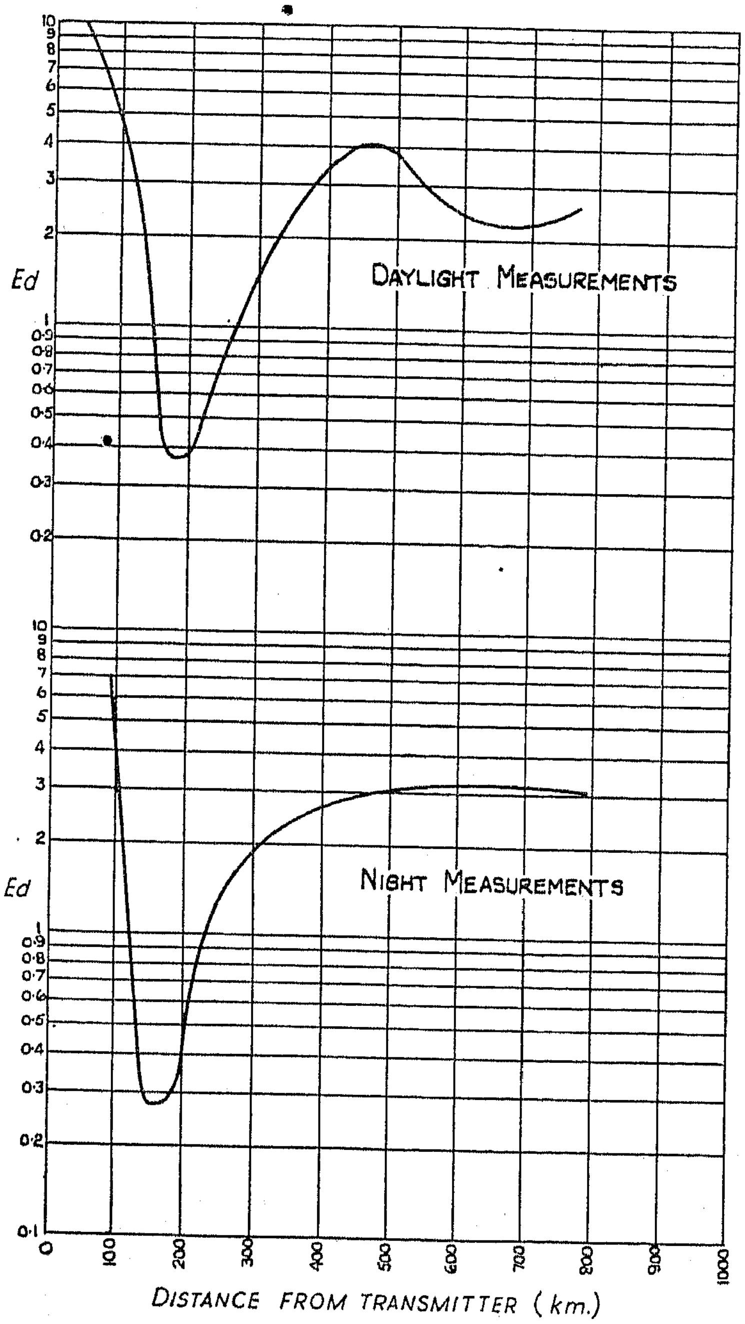

Fig. 19.—Measurements of peak field-strength values.

E = millivolts per metre.
d = distance in km.

The valve type of machine has in the past consisted of one or more triodes connected to a self-oscillatory circuit, the H.T. supply being provided by self-rectification of the output of a step-up transformer connected to the supply mains. These machines are also capable of being operated from about 5 to 10 metres, and in some cases radiate enormously-strong undamped waves both on the fundamental and on numerous harmonic frequencies. The waves are heavily modulated with supply frequency, together with the many low-frequency harmonics introduced by rectification, and constitute interference of the worst possible type. Frequency-wandering and scintillation are usually present to a very great degree, and it is not uncommon for one of these machines to wander into the television band and obliterate television reception over a comparatively large area, as the undamped waves do not appear to be attenuated rapidly, and their effect is noticeable over surprisingly long distances. Later types of valve apparatus have been provided with high-tension rectifiers and smoothing circuits, which to some extent reduce the interference by confining it to a pure wave.

The suppression of interference from these causes is by no means an easy problem, as it is not sufficient merely to screen the apparatus itself and take adequate precautions to prevent the radio frequency being disseminated through the supply mains, since the greatest source of radiation is the patient himself and the leads connecting the machine to the electrodes applied to him. Further, the use of diathermy apparatus is not, in the case of most hospitals, limited to any one room which could be effectively screened, but rather it is the practice to transport the diathermy apparatus to all wards of the hospital, treating patients in their own beds wherever they may happen to be. The problem is thus materially complicated, as clearly it would be a task of great magnitude—if not impracticable—to screen the whole hospital with that meticulous care which experience has shown to be necessary in order effectively to suppress the interference.

One example of the efficiency of comparatively simple methods of screening a room has occurred in the case of a North London hospital situated about ½ mile from Alexandra Palace, where the use of a spark diathermy machine completely jammed the reception at Alexandra Palace of the 5-metre radio-link transmitter. The whole of the walls and ceiling of the room were covered with aluminium foil, 5 mils in thickness, applied with a paper backing after the fashion of ordinary wallpaper. The joints in the foil were of the butt type, a strip of aluminium foil being laid over the intersection and secured in position by means of a batten, so as to be in intimate contact with the foil on both sides of the joint. At one end of the room, which was open, a partition covered with ½-in. mesh chicken-wire was erected, good electrical connection being maintained between the aluminium foil on the ceiling and walls and the chicken-wire. Chicken-wire screens were placed over the window and laid on the floor underneath the usual rubber floor material. Stopper circuits in the form of radio-frequency chokes with condensers to earth were inserted in all electrical leads entering the room from outside, the chokes being placed in suitable screening boxes.

This treatment effected complete suppression of the interference, but the necessity for thorough measures was amply demonstrated by the fact that if the screened door in the partition was opened by only a few inches, the interference appeared at a level comparable with that experienced before the work of screening was carried out.

The existence of high-frequency diathermy apparatus is at present largely confined to the West End of London, where many physicians have their consulting rooms, and to a number of hospitals situated both centrally and in the suburbs. As a result of this the interference, while very violent, is not so widespread as the second form of interference previously referred to, viz. that due to the ignition systems of motor-cars.

Practically all types of motor vehicle, particularly those equipped with coil ignition, radiate more or less serious interference in the television band.

The actual carrying power of this interference is not great, being limited in most cases to a few hundred yards, but, nevertheless, the effect can be extremely serious in the case of the receivers where the aerial is situated in close proximity to a main thoroughfare where a large amount of vehicular traffic is constantly passing.

The two worst cases occur in the centre of the City, where, although the television signal is strong, traffic is particularly dense, and in places towards the fringe of the service area of the station where the television signal is weak and the receiver is situated in close proximity to a main road. The only slightly mitigating circumstance arises from the fact that in the outlying districts the volume of traffic is a good deal less, so that the degree of interference decreases at a rate which is somewhat commensurate with the reduction of signal strength. Even so, extremely bad cases occur in the vicinity of main arterial roads, and the only partial remedy which can be found lies in placing the receiving aerial as far as possible from the source of interference, e.g. at the end of a garden remote from the road, leading into the receiver through a suitably screened or balanced high-frequency cable. The use of directional aerial systems in these cases appears indicated, provided of course that the location of the interference sources does not lie in the same direction as the station.

A curious circumstance noticed is that motor-car interference shows a definite peak at about 125 cycles per sec., and, in fact, on listening it is possible to detect a hum of this frequency preponderating over the general indeterminate noise. It has been suggested that this peculiar frequency of the interference arises from the widespread use of 6-cylinder cars driven at a uniform 30 miles per hour in surrounding limited areas.

Assuming that the average circumference of a car wheel is 5 ft. 6 in. and the average back-axle ratio is 5 to 1, the engine speed would be approximately 40 revolutions per sec., which, for a 6-cylinder engine having a 120° crankshaft resulting in three sparks per revolution, should give a prime interference frequency of about 120 cycles per sec. On this basis, a 4-cylinder engine having two sparks per revolution with 180° crankshaft should give about 70 to 80 cycles per sec., and a certain peak of interference at about this frequency is to be noted, although it does not show up so prominently as the 125-cycle component. The above is mentioned merely as a matter of interest, and as being a possible explanation of a pronounced phenomenon for the existence of which no other convincing reason can at present be advanced.

It has been found possible in practice to suppress the effects of motor-car ignition interference by the inclusion of suitable suppressors in the form of resistances in series with the sparking plugs and distributor, or by completely screening the leads associated with the ignition system by means of an earthed metallic braid. A certain divergence of opinion exists as to whether the taking of these steps has any material influence upon the performance of an internal-combustion engine, but the whole matter is being carefully investigated by the Post Office and the Electrical Research Association with a view to drawing up a definite specification for the suppression of interference due to such causes as motor-cars, diathermy, etc.

(d) Types of Receivers and Receiving Aerials

A number of types of receivers have made their appearance on the market in various forms, but in general the cathode-ray tube appears to be used exclusively as the reproduction medium. The receivers divide themselves broadly into two classes, those using a straight radio-frequency amplification of the vision signal and others employing the superheterodyne principle. Of the latter type there is a further subdivision, viz. those receivers amplifying both sidebands of the transmission and those employing single-sideband operation.

In most cases the detector stage, or second detector in superheterodyne receivers, handles signals of fair amplitude and is equipped with two outputs. One output is usually taken to the control electrode of the cathode-ray tube, either direct or through a single vision-frequency amplification stage, which in some cases is a d.c. amplifier and in other cases is an a.c. amplifier having the d.c. component subsequently restored.

The second output from the detector is usually taken to some form of separator stage, which separates the synchronizing impulses from the vision signals and discriminates between line- and frame-synchronizing impulses. The resultant line- and frame-synchronizing impulses are then fed to the respective line- and frame-scanning oscillators, which are thus synchronized with the incoming signal and provide appropriate sawtooth wave-forms to produce the requisite scan.

The cathode-ray tubes vary in size from 9 in. to 15 in. screen diameter, giving picture dimensions varying from 8 in. × 6 in. to 12 in. × 8 in., and either electrostatic or magnetic focusing and scanning or a mixture of both is used. No definite evidence regarding the relative merits of these principles appears at present to exist. Larger cathode-ray tubes having screened diameters up to 24 in. have been made, but have not yet been generally adopted, as their construction presents rather severe problems, related to the effect of atmospheric pressure.

There appears to be a general tendency to standardize on tubes of 12-in. screen diameter, giving a picture approximately 10 in. × 8 in., although certain makers employ larger tubes and others smaller. The problem of accommodating a cathode-ray tube which may be between 2 ft. and 3 ft. in length in a cabinet of reasonable dimensions has given rise to the exercise of considerable ingenuity in design. The fashion in receivers appears to be fairly equally divided between those in which the cathode-ray tube screen is directly viewed, and those in which it is viewed by means of a mirror forming the top lid of the cabinet. It is generally conceded that the former method of viewing gives greater satisfaction to the viewer, but its use involves severe practical difficulty, necessitating as it does the mounting of the cathode-ray tube in a horizontal position, which in turn implies that the cabinet must be very deep, with the consequence that some difficulty is found in accommodating it in any but large rooms. If, on the other hand, a mirror is used, the cathode-ray tube may be mounted in a vertical position, which results in a cabinet of much more convenient shape. It is of course essential to use front-silvered mirrors to avoid the formation of double images.

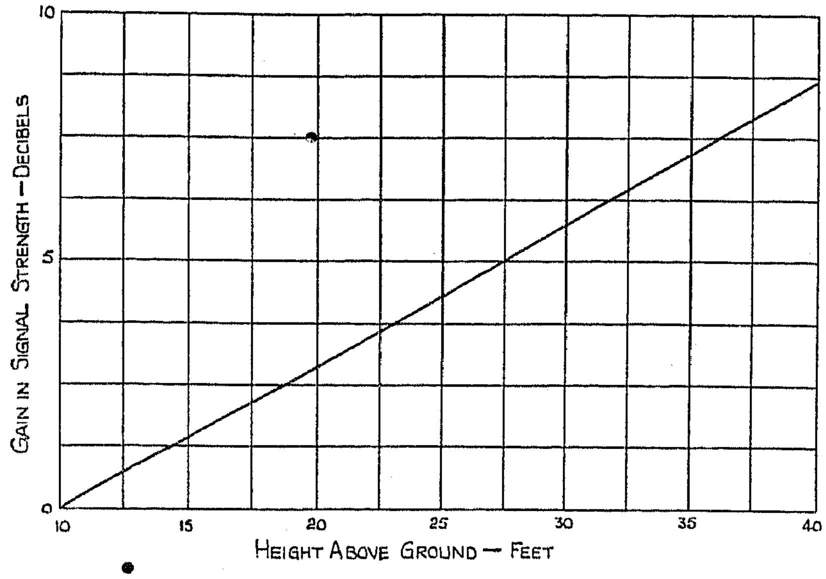

Fig. 20

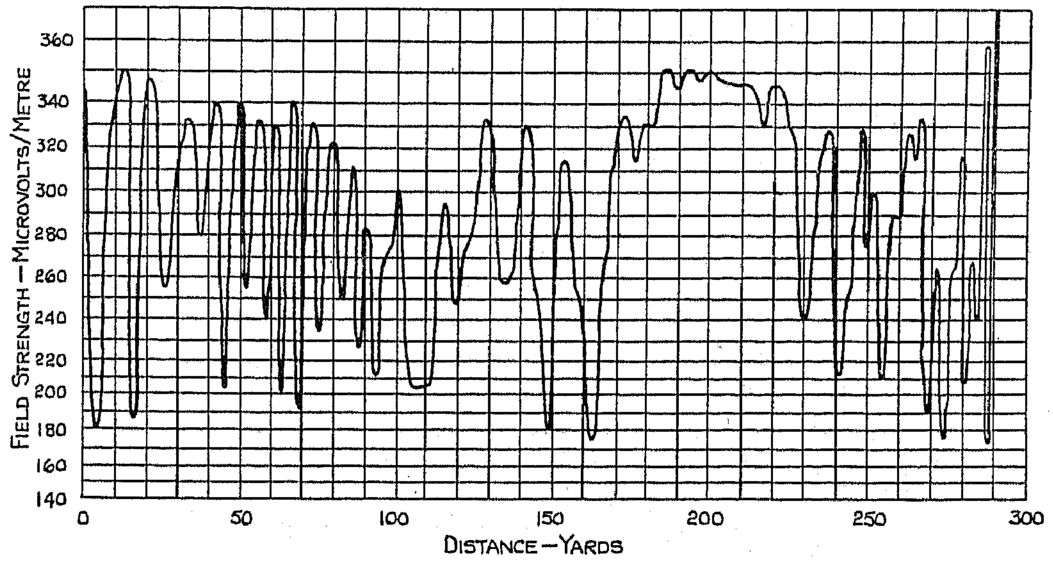

Fig. 21

The advent of television has led to the general use of certain specialized forms of aerials and the development of efficient but inexpensive feeder cables for use with them. The ordinary type of aerial used for sound broadcasting is of but little service for the reception of television, as not only does its response occur at a much higher wavelength, but any attempt to use it as an aperiodic aerial inevitably results in a very poor ratio of signal to interference.

It is the practice, therefore, to mount special types of aerials on the roofs of buildings, often by means of a short mast some 10 ft. or 15 ft. in height, the most general form of aerial to be used being the $\frac{1}{2}$-wave vertical-dipole aerial. This usually consists of a length of copper wire of large diameter, or of small copper tube which is either mounted at its centre so as to be self-supporting or mounted upon the wooden spar by means of stand-off insulators. In the majority of cases the dipole aerial is centre-fed by means of an interruption at its centre point. The two halves of the dipole are frequently connected to a balanced twin feeder having a characteristic impedance of about 120 ohms, so that very fair conditions of matching are obtained. This twin-wire feeder is constructed from two small-diameter copper conductors, embedded very close together in a tube of indiarubber (or gutta percha) and bituminous compound, and has comparatively low losses. It relies upon the proximity of conductors and the fact that it is balanced to ensure that interference due to fields which the cable may traverse cancels out.

An alternative method consists in transforming from a balanced aerial to an unbalanced feeder by means of a $\frac{1}{4}$-wave structure, the feeder in this case taking the form of a coaxial cable, consisting of a central copper conductor and an outside conductor of either lead or copper braid. The space between the conductors is filled up either with paper insulation designed to introduce the maximum of air space or by some low-loss rubber and bituminous compound.

The characteristic impedance of the resultant cable is about 120 ohms, and its losses are relatively low. It relies upon the shielding effect of the outer conductor, which is usually earthed at its lower end, to exclude interference.

Some attempts are made to introduce a measure of directivity into the receiving aerial by mounting a second unfed $\frac{1}{2}$-wave dipole at a distance of $\frac{1}{4}$-wave behind the receiving elements. A gain of from 2 to 3 db. in received signal strength has been recorded for this arrangement. Experiments have been carried out using more complex receiving arrays, including numbers of stack dipoles, inverted V aerials, and various others, but in general these have not as yet been applied to domestic receivers.

As has been previously stated, the effect of height is of great importance. This is illustrated by Fig. 20, showing the gain in field strength plotted against height in a receiving dipole.

Another problem which the receiving aerial brings in its train is the effect of standing waves due to the presence of metal roofs, drainpipes, neighbouring steel-frame buildings, etc. Fig. 21 shows typical effects upon the received field strength which may be encountered by moving the receiving aerial over distances of literally only a few yards. In some cases reflections are received of such delay as to introduce definite multiple images in the received picture, and cases have been recorded where reflections having an extremely long delay have resulted from the existence at some considerable distance of such objects as steel gasometers. Against this, however, it has happily proved to be the experience in general that if some little pains are taken to find a location for the receiving aerial where standing-wave conditions are at their best, and reflections at their minimum, a good result can be obtained in nearly every case.

Sound

Sound reception in practically all television receivers is by means of a separate superheterodyne, operating a loud-speaker suitably placed in the cabinet. In cases where the vision receiver also employs the superheterodyne principle it is not unusual to use a common frequency-changing oscillator for both vision and sound, arranging the intermediate frequency for the sound receiver to be $3\frac{1}{2}$ Mc./sec. lower in frequency than the vision intermediate-frequency.

Receiver Controls

In the case of receivers employing straight radio-frequency amplification of the vision signal, tuning is preset and the only tuning control provided is a trimmer on the frequency-changing oscillator of the sound receiver.

In the case of receivers using the superheterodyne principle for both vision and sound with a common oscillator, an adjustable trimming condenser is usually provided, by means of which the sound signal can be accurately tuned in, arrangements being made before the set leaves the factory that this position corresponds to the optimum tuning point for the vision also.

All types of receivers are provided with a brightness control, which usually varies the standing bias on the control electrode of the cathode-ray tube, and a contrast control which varies either the radio- or the intermediate-frequency amplifier gain or takes the form of a potentiometer across the vision-frequency output after the detector. Some receivers are provided with both of these latter controls, the gain control being used to compensate for variations in signal strength dependent upon the situation of the receiver, and thereafter left untouched. Adjustments to contrast are then made by means of the vision-frequency potentiometer in conjunction with the brightness control, and any desired value of picture contrast may thus be obtained. It is interesting to note that viewers almost invariably seek very "contrasty" pictures at first, but that after a time they tend to reduce the contrast to give a softer effect. The question of colour of the fluorescent screens is of course a matter of taste, and receivers having cathode-ray tubes giving every imaginable shade of green, blue, purple, and sepia, have from time to time made their appearance. While many of these tones are found attractive by some people, the more general taste is for a shade approaching black and white. The majority of receivers now being offered incorporate tubes in which the image is reproduced in a very good range of tones between black and white, with a commendable brightness in the high lights.

ACKNOWLEDGMENTS

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Authors' Note.

Certain of the diagrams illustrating this paper have previously appeared in B.B.C. publications, but in the interests of completeness of this paper it is felt that it is not out of place to reproduce them.

[The discussion on this paper will be found on page 100.]

THE MARCONI-E.M.I. TELEVISION SYSTEM*

PART I. THE TRANSMITTED WAVE-FORM

By A. D. BLUMLEIN, B.Sc.(Eng.), Associate Member.

PART II. THE VISION INPUT EQUIPMENT

By C. O. BROWNE, B.Sc.

PART III. THE RADIO TRANSMITTER

By N. E. DAVIS and E. GREEN, M.Sc., Associate.

(*Paper read before* THE INSTITUTION 21*st April*, 1938.)

INTRODUCTION

The object of this paper is to describe the radiated wave-form of the Marconi-E.M.I. television system and electrical equipment supplied to the B.B.C. for the London Television Station. Owing to the wide field covered, the paper is written in three Parts, which are in effect three separate closely-related papers.

PART I

THE TRANSMITTED WAVE-FORM

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(*First received* 1*st December*, 1937, *and in final form* 12*th March*, 1938.)

SUMMARY

This Part of the paper describes the technical considerations leading to the choice of the particular wave-form now standardized by the B.B.C. for radiation from the London Television Station. The various characteristics of the system are described, together with the considerations that led to their adoption. A slight modification of the published wave-form specification is suggested. Finally, automatic volume control is briefly discussed. An Appendix gives the modified wave-form specification.

(1) INTRODUCTION

A system of television, inasmuch as it is chosen for standardization in a particular country or district, is characterized not by the use of a particular type of camera, nor by the use of electrical or mechanical scanning, but by a specification of transmitted wave-form. The fixation of a wave-form may almost certainly imply the use of particular types of apparatus at the transmitter, but such apparatus is largely subservient to the standard chosen. The following paragraphs describe the considerations which led to the choice of the present Marconi-E.M.I. wave-form standard. Headings are given to the sections covering various features of the transmitted wave-form, but a certain amount of overlapping is inevitable owing to the interdependence of the factors involved.

(2) UNIDIRECTIONAL CONSTANT-VELOCITY SCANNING

Although "zigzag" scanning, i.e. scanning where alternate lines are scanned in opposite directions, is attractive for electrical scanning on account of the absence of any very rapid changes of scanning field, its use was not seriously considered in view of the fact that it is unsuitable for mechanical scanners, and also in view of the intolerable accuracy of the scanning wave-form and synchronization required if good pictures are to be reproduced.

Another possible system was one where the scanning velocity depends upon the picture brightness. A complete description of such a velocity-modulated television system is given in Messrs. Bedford and Puckle's very interesting paper.[†] In this system the velocity of scanning was varied in accordance with the brightness of the area scanned. For high lights the scanning velocity was inversely proportional to the brightness. For dark tones, however, a conventional maximum velocity represented black, brightness control being used at the receiver to supplement the variations in apparent brightness produced automatically by the variable velocity. Apart from convenience or inconvenience of constructing the necessary transmitting and receiving apparatus, velocity modulation from the transmission standpoint is characterized by "implicit" synchronization, in that the scanning-control signals and the brightness-control signals are one and the same. This avoids the necessity for any special synchronizing signals. On the other hand, the position of the scanning spot is an integral of the brightness and conversely the brightness is a differential of the spot position, which leads to serious interference troubles in transmission. These troubles, which are examined in the above-mentioned paper and the discussion following it, were sufficiently fundamental to preclude the use of velocity modulation.

A system was adopted having all the lines scanned in the same direction at uniform speed, which necessitates the transmission of distinct synchronizing and vision signals.

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* Reprinted from *Journal I.E.E.*, 1938, vol. 83, p. 758.

[†] *Journal I.E.E.*, 1934, vol. 75, p. 63; and *Proceedings of the Wireless Section*, 1934, vol. 9, p. 173.

(3) MODULATION: A LINEAR FUNCTION OF OBJECT BRIGHTNESS

The vision signals to be transmitted represent from instant to instant the brightness of the picture being scanned, and may have any amplitude between a value representing black and a value representing the brightest part of the picture or " white." The signals may change gradually, as for a gradual shading of the picture, or very rapidly, as for a vertical edge, the ultimate rapidity of change being limited by the size of the transmitting scanning-spot and the frequency-limitations of the transmitting circuits. It should be noted that the vision signals essentially contain all frequencies down to zero and lie one side of the datum level, which is black. The signals in this respect are more akin to telegraph signals than telephone signals. It has been considered whether better transmission could be obtained by distorting the transmitted wave-form from that directly representing brightness, by distorting the frequency characteristic before transmission and correcting at the receiver. A short consideration will show that practically any frequency within the range may be produced at full black-to-white amplitude; so that, if the picture transmitted is not prescribed, any frequency distortion will reduce the transmitted level of some frequencies without enabling the level of any others to be increased. As far as possible, therefore, the vision signals are transmitted with a flat frequency-characteristic.

In current cinematograph technique it is usual to increase the contrast by a factor lying between $1 \cdot 5$ and $2 \cdot 0$, presumably to make up for lack of colour. This factor is usually called γ, the original brightness A of any point being related to the reproduced brightness B by the relation $B = kA^{\gamma}$. Since the eye is approximately logarithmic, this leads to an increase of contrast of approximately γ. This same effect is required in television. The question naturally arises as to whether this should be applied at the transmitter or the receiver. Now a given small change in light intensity at the picture is more noticeable in dark than in light parts of the picture. With a linear characteristic at the receiver, the dark parts of the picture are liable to suffer severely from quite slight interference. By applying the correction at the receiver the sensitivity of the receiver is rendered lower for low light-intensities, so that slight interference is not so noticeable. It is advantageous, therefore, to transmit pictures with unity γ and make any correction at the receiver. This is convenient since any unidirectional control, such as the control of beam current in a cathode-ray receiving tube, is likely to be curvilinear in the required sense. Theoretically, assuming a logarithmic sensation law for the eye, a logarithmic transmitting distortion with exponential receiving characteristic is indicated, but such an arrangement is hardly considered practicable, if really desirable; and so far, despite its advantages, has seldom if ever been applied even to sound transmission.

The above arguments lead to the transmission of a signal, as far as possible undistorted in frequency or amplitude, representative of the brightness of successive elements of the picture scanned with a constant scanning velocity.

(4) DOUBLE-SIDEBAND AMPLITUDE MODULATION

The next consideration is the modulation of a radio signal for broadcasting. It was considered that phase modulation of a wave containing frequencies down to and including zero would give a wave which could not be demodulated at the receiver without resorting to some special device such as another radiated carrier at multiple frequency which could be used as a reference carrier. Single-sideband working at the transmitter was similarly considered, in the hope of reducing the space occupied in the ether. No advantage would be obtained by such an arrangement unless one sideband was suppressed substantially completely, at least for all but the lowest modulation frequencies. In view of the necessary wide band-width extending down to zero frequency, and the strict phase requirements for television transmission, no practicable method of single-sideband transmission was discovered. The mere tapering-off of signal strength for one of the sidebands has no particular advantages for the transmitter. A straightforward double-sideband amplitude modulation was therefore adopted.

(5) "INFRA-BLACK" PULSE SYNCHRONIZING

Before considering the direction and range of modulation, it is necessary to consider how the synchronizing signals are to be transmitted. For convenience of reception it is very advantageous to transmit the synchronizing signals on the same carrier as the vision signals. Furthermore, although in the case of a perfectly uniformly-running scanning system there is no continuous transmission of intelligence by synchronizing signals, nevertheless it is highly advantageous under practical working conditions to provide the receiver with an accurate synchronizing signal between each line and the next, so that a satisfactory picture may be obtained with scanning circuits composed of comparatively unstable commercial components. In fact, it is desirable that the synchronizing signals should be such as to permit of a receiver being worked asynchronously, much after the manner of a "start stop" telegraph printer. This requirement calls for line signals of a sharpness comparable with the vision signals, i.e. containing a wide band of frequencies. A further increase of the required band-width due to supplying a sub-carrier or separate carrier for the synchronizing signals appears highly undesirable, and the synchronizing signals are therefore transmitted on the same carrier as the vision signals, being differentiated therefrom by difference of amplitude of modulation.

As explained above, the vision signals lie within a range limited by black and white (representing the brightest part of the picture). Synchronizing signals can therefore be transmitted as signals lying beyond the black or white, outside the vision-signal range. Such signals may be spoken of as " blacker than black " or " infra-black " if outside the vision-signal range in the black direction, or " whiter than white " or " ultra-white " if outside in the white direction. If ultra-white synchronizing signals are employed it is necessary to provide special and rather complicated means at the receiver to prevent these synchronizing pulses from appearing on the picture. If synchronizing signals are employed in the infra-black these signals will not, with the majority of receiver types, appear on the receiver screen, since the majority of light-control devices are unaffected by a signal greater than that necessary to obscure the light. This great advantage of requiring no special synchronizing signal-obscuring device at the receiver has led to the adoption of infra-black synchronizing signals. In this connection it should be noted that there is a possible workable system employing ultra-white synchronizing pulses extending down to zero radiated carrier, with black representing peak carrier. This system has the merit of providing simple A.V.C. (automatic volume control) and noise suppression at the receiver, but on the other hand a comparatively complex arrangement is necessary for preventing the ultra-white signals from appearing on the screen. The infra-black system adopted can supply A.V.C. and noise suppression with no more, or even less, complex equipment than is required for pulse suppression by the above ultra-white system. Further, for a simple receiver the infra-black receiver is less complex than the ultra-white.

(6) D.C. TRANSMISSION*

Before discussing the exact form of synchronizing pulses it is necessary to consider what is known as d.c. working. Owing to the difficulties of making satisfactory high-gain d.c.-coupled amplifiers, most television amplifiers have in the past been a.c.-coupled, so that the resultant vision wave has been an a.c. wave, lying about a mean value, rather than a d.c. signal referred to a datum level of black. Now with an a.c. television signal the amplitude of black relative to the mean line is a variable amount depending on the nature of the picture. With a white dot on a black background the black will be close to the mean line. For a black dot on a white background, the black will lie remote from the mean line. A change in the nature of the picture will cause a wander of the amplitude of the black signal. Now at the receiver it is necessary to separate the vision signals from the synchronizing signals so that the latter may be used to control the scanning. An "infra-black" synchronizing signal can be separated by a "separator" device set to pass signals beyond a certain amplitude in the black direction. If, however, the black level is liable to wander at the separator, it is necessary to employ large synchronizing signals so that no possible amount of "wander" will cause either vision signals to be passed by the separator or synchronizing signals to be missed by the separator. The size of the synchronizing signal required at the receiver may be greatly reduced by ensuring that the signal at the separator is a d.c. signal, i.e. a signal having a definite amplitude for black irrespective of the nature of the picture. The d.c. signal may be obtained either by transmitting the d.c. signal or by converting the a.c. signal to a d.c. signal by "d.c. re-establishment" at the receiver. This latter process relies on the synchronizing signals being of fixed amplitude and comparatively free from interference. The same "wander" which makes separation difficult with an a.c. signal, causes an a.c. signal to be unsatisfactory from the transmission standpoint. As the black-to-white amplitude is fixed, the liability of the absolute value of black to wander means that the whole signal may occupy a range of absolute values greatly in excess of the difference between black and white. It is therefore necessary to provide larger equipment to accommodate the extra amplitude-range produced by the "wander." Furthermore, any slight amplitude-characteristic curvatures will variably affect the signals as the "wander" takes place. The transmission of an a.c. modulation therefore involves for a given available transmitter-power much smaller useful signals at the receiver; and, although the difficulty of synchronization-signal separation can be got over by d.c. re-establishment at the receiver, this may not be very satisfactory in the presence of interference, especially as with a.c. transmission the synchronizing signals cannot, owing to the wander, be kept in a part of the modulation characteristic comparatively free of strong interference [see tests described in Section (6)]. The transmission of a d.c. modulation has therefore been chosen, i.e. definite carrier values represent black, white, and the synchronizing signal. There is no fixed mean carrier value, as this depends on the picture brightness. The system of transmission is analogous to telegraphy rather than telephony.

For lack of a better word, "carrier" is here used as representing the instantaneous radio-frequency output of the transmitter in amperes or volts in the aerial, the reference value being the peak output of the transmitter. This use differs from that employed for telephony transmission, where the word "carrier" refers to what would be called "mean carrier" or "average carrier" in this paper.

(7) POSITIVE MODULATION AND 30 % SYNCHRONIZING PULSE

"Infra-black" synchronizing and d.c. transmission having been decided upon, it remains to fix the direction and limits of modulation. If the synchronizing signals are represented by a high carrier ("negative modulation") they will be very prone to interference, which increases the amplitude and so, in effect, produces at the receiver super-strong synchronizing pulses. Such strong pulses may greatly disturb the picture-scanning. On the other hand, white being represented by a low carrier value, larger ultra-white signals than those represented by zero carrier cannot be produced, and this reduces the brightness of severe interference. If, however, "positive modulation" is employed, in which synchronizing signals are represented by a low (and, very preferably, practically zero) carrier while white is represented by a high carrier, super-strong interfering synchronizing pulses cannot be experienced. This enables comparatively small synchronizing signals to be employed while satisfactory synchronization is still given. With this arrangement strong ultra-white signals can be produced by interference, but these signals are less irritating than the breaking-up of the picture produced by the interference giving super-strong synchronizing pulses. Of course, with negative modulation a carefully designed limiter could be used at the receiver to ensure that the scanning generators could only be affected by signals of the exactly correct amplitude. It is thought that such a limiter would be very difficult to adjust for all reception conditions, and if made self-adjusting would be upset by very severe interference. A similar limiter, not requiring as sensitive an adjustment, may be used for suppressing interference when positive modulation is employed.

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* P. W. WILLANS: British Patent No. 422906 (E.M.I.)

Tests were carried out some years ago from Hayes, Middlesex, to St. John's Wood in order to compare positive- and negative-modulation reception in the presence of interference. The initial tests were made using synchronizing signals equal in amplitude to the vision signals. With negative modulation the interference gave rise to breaking-up of the whole picture. A considerable improvement was obtained by changing to positive modulation, the white flashes produced by interference being much less irritating than the breaking-up of the picture. Better results still were obtained by modulating so that the synchronizing signal was represented by practically zero carrier. With this condition satisfactory synchronizing under interference conditions could be obtained with synchronizing signals of only one-fifth the vision amplitude. No interference can possibly produce a field strength, and hence detector output, less than zero, so that by modulating down to zero carrier for synchronizing signals no super-strong interfering synchronizing pulses can be produced, and hence very good interference-free synchronizing is obtained at the receiver. These tests led to a definite decision to adopt a system with substantially zero carrier representing the synchronizing signal and with peak carrier representing white. The diminishing return of increased vision signals produced by reducing the synchronizing signal down to one-fifth the vision signal led to the adoption of a synchronizing signal of three-sevenths of the vision signal.

(8) CONSTANT-AMPLITUDE RECTANGULAR SYNCHRONIZING PULSES

A further advantage of working down to zero carrier with the synchronizing pulses is that these pulses occupy the necessarily curved bottom bend of the transmitter modulation characteristic, so that efficient use is made of a part of the characteristic unsuitable for vision signals. It is of course necessary that a d.c. modulation be employed, both to prevent the synchronizing signals from wandering away from zero carrier and to prevent them being crushed out altogether round the bend of the characteristic. Provided all synchronizing signals are made rectangular in wave-shape and of equal amplitude, the operation on a curved characteristic does not affect their shape but only their size, which can be allowed for by increasing the input of synchronizing signal to the modulator. Furthermore, it is practically necessary for the line-synchronizing signals to have a square (within the limits of the frequency range) leading edge in order to achieve accurate synchronizing as explained above. All synchronizing signals have therefore been made rectangular and of equal amplitude so that they can suffer amplitude distortion without distortion of shape. This feature is most important, as it allows the synchronizing signals to be crushed considerably without losing timing accuracy. Furthermore, they may be restored, if desired, to their original amplitude after crushing; this feature is of some importance when radio relays are being operated.

(9) 50-FRAMES-PER-SECOND INTERLACED SCANNING

At the beginning of 1934, when the originators of the system here described were working with 180 lines and sequential scanning at 25 frames per sec., the cathode-ray receiving tubes used were not at all bright. With a poorly illuminated picture at the receiver the 25-cycle flicker was not very objectionable, but as receiving tubes became brighter it was obvious that 25-cycle flicker would be unacceptable in practice. The present system of interlacing was therefore adopted.* In such a system the picture is completely scanned in $\frac{1}{25}$ sec. by means of two downward traversals or frames, each of $\frac{1}{50}$ sec. duration. The lines constituting one such frame are arranged to lie between the lines of the other frame so as to give good picture detail. The process is analogous to the device used in film projection, whereby it is arranged that although only 24 pictures are shown per second, each picture is thrown on the screen 2 or 3 times so as to raise the light-flicker frequency to 48 or 72 flashes per sec. Similarly, with interlaced scanning the spot traverses the frame 50 times per sec., thus raising the flicker above that perceptible to the human eye. The feature of this particular interlacing system is that both the line-traversals and the frame-traversals are entirely regular, the interlacing being effected by fixing an odd number of lines to a complete picture, i.e. an integer plus a half number of lines to each frame. With regular scanning traversals, an interlaced picture results. This process is explained in greater detail in the Appendix.

A frame frequency of the order of 50 was necessary in order to overcome flicker, and the exact value 50 was chosen on account of the supply frequency in this country. Receivers built to operate from the 50-cycle mains, always have some slight residual hum which either darkens or brightens parts of the picture, or produces a slight distortion of the frame. If the frame frequency is synchronous, or very nearly synchronous, with the supply frequency, these effects are stationary, or move very slowly across the picture, in which case they are not nearly so noticeable to the eye as when moving rapidly across the picture. Experiments on a cathode-ray-tube receiver worked from 50-cycle mains showed that residual-hum effects which could not be detected when scanning took place at 50 frames per sec. were quite intolerable at 37·5 frames per sec. Furthermore, the smoothing and magnetic shielding required for operating at 37·5 frames per sec. were such as to increase the cost and size of receivers very seriously. It was therefore decided to adopt 50 frames per sec. and where possible to hold this frequency in synchronism with the grid supply.

(10) 405-LINE SCANNING

After the 180-line scanning mentioned above had been abandoned, a system was adopted using a 243†-line picture at 50 frames per sec. (interlaced) to give 25 complete pictures per sec. It was decided, however, to recommend to the Television Commission a specification based on 405 lines, so as to provide a system which might remain stable for a reasonable length of time. This recommendation was not given without considerable misgivings, since it involved an increase of 67 % in the line-scanning speed and an increase of 2·8 times in the frequency band-width over those employed for the 243-line system which had recently been developed. These misgivings were in no way allayed by the thought that the system must work in competition with a developed 240-line system, which might in the initial stages give more detail on early receivers of poor band-width. During the period before the station operated, however, transmitting apparatus was considerably improved and the receiver manufacturers designed good receivers, so that tolerably good 405-line pictures were obtained. It is a considered opinion that the present transmitted and received pictures can be considerably improved in detail without exhausting the possibilities of the present system.

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* R. C. Ballard: British Patent No. 420391 (R.C.A.).

† The number 243, and also the later number 405, were chosen as being multiples of small odd integers, which facilitated the electrical interlocking of the line and frame frequencies required for interlacing.

(11) INTERVALS BETWEEN LINES AND FRAMES

The values 50 frames per sec. and 405 lines having been chosen, it was necessary to determine arbitrarily the time-intervals between successive lines and frames to which the receiver must be designed to work. These time-intervals are needed at a cathode-ray receiver for the return stroke, by which the cathode-ray beam is returned from the end of one line or frame to the beginning of the next. Actually the beam is turned off, or " blacked out " during the return stroke, nevertheless the electric or magnetic field controlling beam-deflection must be altered just as though the beam were there to perform the return stroke. Obviously such electric or magnetic fields cannot be altered instantaneously at the end of each line or frame, and thus time-intervals are necessary if some of the picture is not to be missed. With mechanical receivers using rotating scanning means, successive lines are scanned by different mechanical elements, so that one line may be scanned from the instant the previous line-scan terminates. With such an arrangement, absolutely perfect phase synchronization would be necessary to prevent the beginning of a picture being cut off and folded round to the end of the picture. Intervals between lines and frames therefore provide a small black edge round the picture which allows for a small phase-error in the mechanical scanning.

Owing to various difficulties with the original 243-line scanning equipment, the transmitted picture originally had intervals between successive lines of about 35 % of the line period, and between successive frames of about 20 % of the frame period. This meant that only 65 % of the line and 80 % of the frame was employed, giving a time (or frequency band-width) efficiency of only 52 %. It was obvious at the time that this efficiency would ultimately be considerably improved, and it was therefore decided to fix the minimum transmitted intervals between lines to which receivers must be designed, and to improve the transmitter as much as possible as time went by—until the minimum intervals were effective for the transmitted picture. The transmission of pictures with longer intervals between lines than are required by the receiver produces only a black border round the picture and consequently a diminution of received picture size or detail. On the other hand, the transmission of intervals shorter than the receiver is designed to take will cause a folding-over of the picture and consequently poor or useless results. The minimum intervals were therefore fixed with reference to receivers only, so that even if the transmitter failed to realize these short intervals initially it could be improved later to enable it to give full efficiency. At the same time these minimum intervals were inserted in the wave-form specification so that receivers could be designed with reference to possible future transmissions.

Considering cathode-ray receivers, the total line period for a 405-line system is approximately 100 microsec. (more exactly, 98·8 microsec.), whereas a frame period is 20 000 microsec. It is therefore obvious that it is possible to reverse the scanning field (electrostatic or electromagnetic) in a shorter fraction of the frame period than the line period. The intervals between frames may therefore be a smaller fraction of the frame period than the intervals between lines are of the line period. On the other hand, the intervals between frames should be longer than the intervals between lines, and this for two reasons. First, the frame frequency is much lower than the line frequency, so that the electrical components of the frame-scanning circuit (transformers, and coupling condensers) have longer time-constants and are usually physically bigger, and thus the unwanted strays are greater than for the line-scanning circuit. This makes it more difficult to reverse the frame-scanning field quickly (say, in less than the duration of one line). Secondly, since all synchronizing pulses are rectangular and of equal amplitude the frame signals are differentiated from the line signals only by the long duration of the former. If the frame-scanning signals only are to trip the frame-scanning mechanism, some time must elapse between the end of the picture signals of one frame (which is the earliest moment that the frame-synchronizing signals can conveniently be transmitted) and the beginning of the frame return stroke, in order that the long frame-synchronizing signal may be transmitted and operate the receiver. The interval between frames was therefore fixed arbitrarily at about one-third the fraction of the frame that the interval between lines was of the line.

It appeared also that the intervals between lines must be fixed arbitrarily, there being no means of calculating a " correct " value. On the one hand the natural desire to save time and the belief that scanning-circuit technique would improve, called for a short interval. On the other hand, the necessity of keeping receiver costs down, and the probable future use of very high voltages and big beams with consequent large stored scanning-field energies, called for a long interval. After much consideration the minimum interval between the picture signals of successive lines was fixed at 15 % of the total line period (14·8 microsec.), and the minimum interval between the vision signals of successive frames was fixed at 10 lines (4·94 % of the total frame period). This gives a time efficiency of 80·8 %. Any attempt to raise this figure to 90 % would lead to very severe difficulties in connection with scanning cathode-ray receivers. As regards mechanical receivers, it appears also reasonable to give a bigger percentage interval between lines, since the scanning speed is high for lines and the phase accuracy probably more difficult to obtain.

(12) WAVE-FORM SPECIFIED

The main technical considerations affecting the system having been fixed, it remains to fix conventions of scanning directions, the picture height/width ratio, and the duration of synchronizing impulses. The Appendix gives a specification of the radiated wave-form, together with an explanatory drawing. This specification is similar to that published at the beginning of October, 1935, except for the two slight modifications which are described below.

The direction of line and frame scanning was arbitrarily chosen as left to right and top to bottom, in deference to the normal writing directions. The ratio of picture width to picture height was chosen as 5 : 4, as a compromise between 1 : 1 to give maximum area in a circular cathode-ray tube and the 3 : 2 ratio popular in photography. The line-synchronizing signals occupy the first 10 % of the 15 % intervals between lines, leaving a minimum 5 % " black " interval between the end of a line-synchronizing pulse and the beginning of the picture signals. It might be argued that, there being 15 % available, the whole period should have been used for the synchronizing pulse. Actually, except under conditions of very severe and rather freak interference, a line-synchronizing pulse of 1 % or 2 % would be adequate, since only the leading edge of the line pulse is used in practice to trip the line-scanning mechanism. The use of all of a 10 % pulse would only leave 5 % for the whole mechanism of the return stroke. Further, the 5 % black is extremely useful. Without it the only indication of the level of black would be the intervals between synchronizing pulses between frames, which only occur every $\frac{1}{50}$ sec., and represent a very small fraction of the total time of a frame. The 5 % black between lines gives a continuous indication of black level, line by line, which is of great value both for adjusting the transmitted wave by observation of an oscillograph, and for controlling it electrically. For example, the receiver used to receive a radio signal from the mobile transmitter for outside broadcasts has a high-speed A.V.C. to deal with possible reflections from moving objects in the vicinity of the transmitting aerial. This control is worked by observing electrically the received amplitude-difference between synchronizing impulses and this 5 % black.

It is very desirable in cathode-ray-tube receivers to keep the line-scanning mechanism running smoothly during the interval between frames. With this object in view the frame-synchronizing signal is broken up into pulses so that the leading edge of a pulse replaces the leading edge of a line-synchronizing pulse.* Leading edges of synchronizing pulses therefore occur regularly at line frequency throughout the transmission. Since half the frame-synchronizing signals occur half a line out of step (relative to the lines) with the other half, the frame signals are broken up at double line-frequency, so that the total frame signal is identical in each frame. The total frame-synchronizing signal is therefore composed of a number of signals 40 % of a line long separated by 10 % of a line, two such pulses and two intervals occupying a total line. The 10 % interval allows a suitable differentiating circuit in the line-scanning control to accept the leading edge of the frame-synchronizing signal in place of the leading edge of the line signal. As originally specified there was any number of frame pulses between 6 and 12, no definite number being stated, since it did not appear to be of interest to the receiver manufacturer and it was then thought that the exact number would be rather difficult to control at the transmitter. The B.B.C. have fixed the number of pulses at 8. These occupy 4 out of the minimum 10 lines' interval, and for the remaining 6 lines normal line-synchronizing signals with black picture signals between are transmitted. Again, it might be argued that the whole interval between frames should be filled with frame signals. Eight frame signals represent 32 times the integrated synchronizing-signal strength of a line signal, which should be sufficient for differentiating between the two types of signal. Further, the 6 lines of black give the line-scanning mechanism a chance, before the picture begins, to recover from any slight upset due to being operated from long frame-synchronizing pulses instead of short line pulses. The specification given in the Appendix has been modified to fix the number of frame pulses at 8.

(13) WAVE-FORM ACTUALLY RADIATED

Transmissions using the wave-form specified above have been radiated from Alexandra Palace for over a year, and the wave-form adopted has, it is thought, proved reasonably satisfactory. The intervals between transmitted line vision signals have been reduced to practically the specified minimum, except for a small additional interval before the synchronizing pulse (which will be dealt with below). The interval between frames has not been reduced to the minimum 10 lines, owing to the method of film scanning at present employed. An interval of 20 lines is employed, 5 of the additional " black " lines being put in before the synchronizing pulse and the remaining 5 being added on to the end of the specified 10-line minimum interval. That is to say, between frames there occur 5 black lines before the beginning of the frame-synchronizing signal, and 15 black lines after the beginning of the frame-synchronizing signal, these 15 lines including, of course, the 4 lines occupied by the frame-synchronizing pulses. It would be possible to send direct vision pictures (anything other than cinema film) with the minimum 10 lines' interval, but such a procedure would mean rather extensive re-adjustment of the apparatus prior to transmitting film. Such a procedure is unworkable at Alexandra Palace, where film transmissions are interspersed with studio pictures, the two often being worked in conjunction. It is hoped in the future, however, that the method of film transmission will be altered so as to allow the minimum 10-line interval to be realized from the transmitter. Such a change appears trivial, but it does represent a 5 % improvement in effective picture detail, and is considered to be well worth while.

The original specification of radiated wave-form was incomplete in one respect. As specified under minimum-interval conditions, and as shown on the drawing, the beginning of line-synchronizing signals was coincident with the end of the vision signals of the line. Such coincidence with instantaneous change from white to synchronizing is impossible with finite frequency band-widths. Even were such a signal radiated, it would lead to trouble in a receiver of finite band-width, inasmuch as the line synchronizing would be affected by the vision signals immediately preceding the line-synchronizing signal. The effect of this would be a slight distortion of vertical edges in dependence on the signal brightness on the right-hand edge of the picture. The specification should have contained a reference to a minimum additional interval prior to the line-synchronizing signal of 0·5 % of a line, making the total minimum interval between the vision signals 15·5 %, of which 0·5 % precedes and 15 % follows the beginning of the line-synchronizing signal. This additional minimum interval has in fact always been present in all transmissions radiated from Alexandra Palace on the Marconi-E.M.I. system, the apparatus being set to give an interval of between 0·5 % and 1 % between cessation of vision signals and beginning of line synchronizing. The existence of some interval between vision and synchronizing signals is a practical necessity at the transmitter, so as to give a tolerance which ensures that the vision and synchronizing signals do not get mixed. On the other hand, a reference to the minimum value of the interval should have been made in the specification, since such a minimum value is of slight interest to the receiver manufacturer, as indicating the frequency band-width necessary in order to obtain perfect separation of synchronizing signals. The specification given in the Appendix has been amended to correct this defect.

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* W. S. Percival, C. O. Browne, and E. L. C. White: British Patent No. 425220 (E.M.I.).

(14) AUTOMATIC VOLUME CONTROL

Before closing this discussion of the system specification it is well to consider whether the wave-form provides for facilities which may be required in the future. It has often been pointed out that an a.c. transmission system provides automatic volume control (A.V.C.) for television in the same manner as it is available for sound reception. With an a.c. system, however, the A.V.C. must certainly operate very slowly so as to be unaffected by frame frequency, and therefore it will not be suitable for correcting variations of signal-strengths due to objects moving rapidly near an aerial. Further, the simplification of A.V.C. claimed will hardly justify the increased receiver size necessary to avoid overloads from "wandering" signals, and the reduced signal-strength due to poor use of the transmitter.

Again, it has been pointed out that a d.c. transmission with negative modulation provides simple A.V.C. by observation of the peak synchronizing amplitudes. This is admittedly the case, but any simplicity of A.V.C. is, it is thought, outweighed by the complexity of the limiter necessary to suppress false synchronization.

With the system here described, A.V.C. has not in general been found necessary on the wavelengths at present used. Were an A.V.C. required, however, the necessary control might be obtained by observing the black-level amplitude which always follows a synchronizing signal. The necessary pulse for controlling such a device can, for example, be obtained by differentiating the synchronizing pulse and using the trailing edge. There are a number of circuit arrangements available, and the extra equipment involved constitutes a small addition to the multi-valve television set. Furthermore, with synchronizing signals extending to zero, the arrangement can be made such that it cannot "lock" in a position of maximum receiver sensitivity, provided this maximum sensitivity is not so great as to overload the receiver completely with surface noise. If desired, a limiter may then be added to suppress interference flashes on the screen, the setting of the limiter being much less critical than in the case of the limiter which is practically a necessity for a negative-modulation system.

(15) ACKNOWLEDGMENTS

The fixation of the system described in this paper is the result of many years of experimental work and discussion in the Research Laboratories of Electric and Musical Industries, Ltd., in which many engineers were involved. Acknowledgments are due to Mr. I. Shoenberg, the Director of Research; to Mr. G. E. Condliffe; and to the staff of the Research Department. Among the many members of the staff who made valuable contributions to this work are Mr. C. O. Browne and Mr. P. W. Willans.

APPENDIX

Amended Specification of Radiated Wave-form

The Marconi-E.M.I. television system transmits 25 complete pictures per sec., each of 405 total lines. These lines are interlaced so that the frame and flicker frequency is 50 per sec. The transmitter will radiate signals with sidebands extending to about 2·5 Mc./sec.* on either side of the carrier frequency. The transmitted wave-form is shown in Fig. 1.

(a) Line frequency.

10 125 lines per sec., scanned from left to right when looking at the received picture.

(b) Frame frequency.

50 frames per sec., scanned from top to bottom of the received picture.

(c) Type of scanning.

The scanning is interlaced. Two frames, each of 202·5 lines, are interlaced to give a total of 405 lines with a complete picture speed of 25 per sec. The line component and the frame component of scanning are regularly recurrent, the interlace being derived from the fractional relationship between line and frame frequencies. An explanation of the method of interlacing is given at the end of this specification.

(d) Interval between lines.

There will be intervals between the vision signals of successive lines; these intervals provide time for the transmission of a line-synchronizing signal and also for the return of the cathode-ray beam to the beginning of the next line. The minimum interval between the vision signals of successive lines will be 15·5 % of the total line period (1/10 125 sec.); the first 0·5 % of this interval corresponding in intensity to black and constituting a short black interval separating vision signals from the beginning of the line-synchronizing signal; the next 10 %

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* The original specification gave the modulation band as 2·0 Mc.

being occupied by the line-synchronizing signal; and the remaining 5 % again corresponding in intensity to black and separating the end of the line-synchronizing signal from successive vision signals.

(e) Interval between frames.

There will be intervals between the vision signals of successive frames. The minimum interval between frames will be 10 lines, leaving a maximum of 192·5 active lines per frame, or 385 active lines per complete picture.

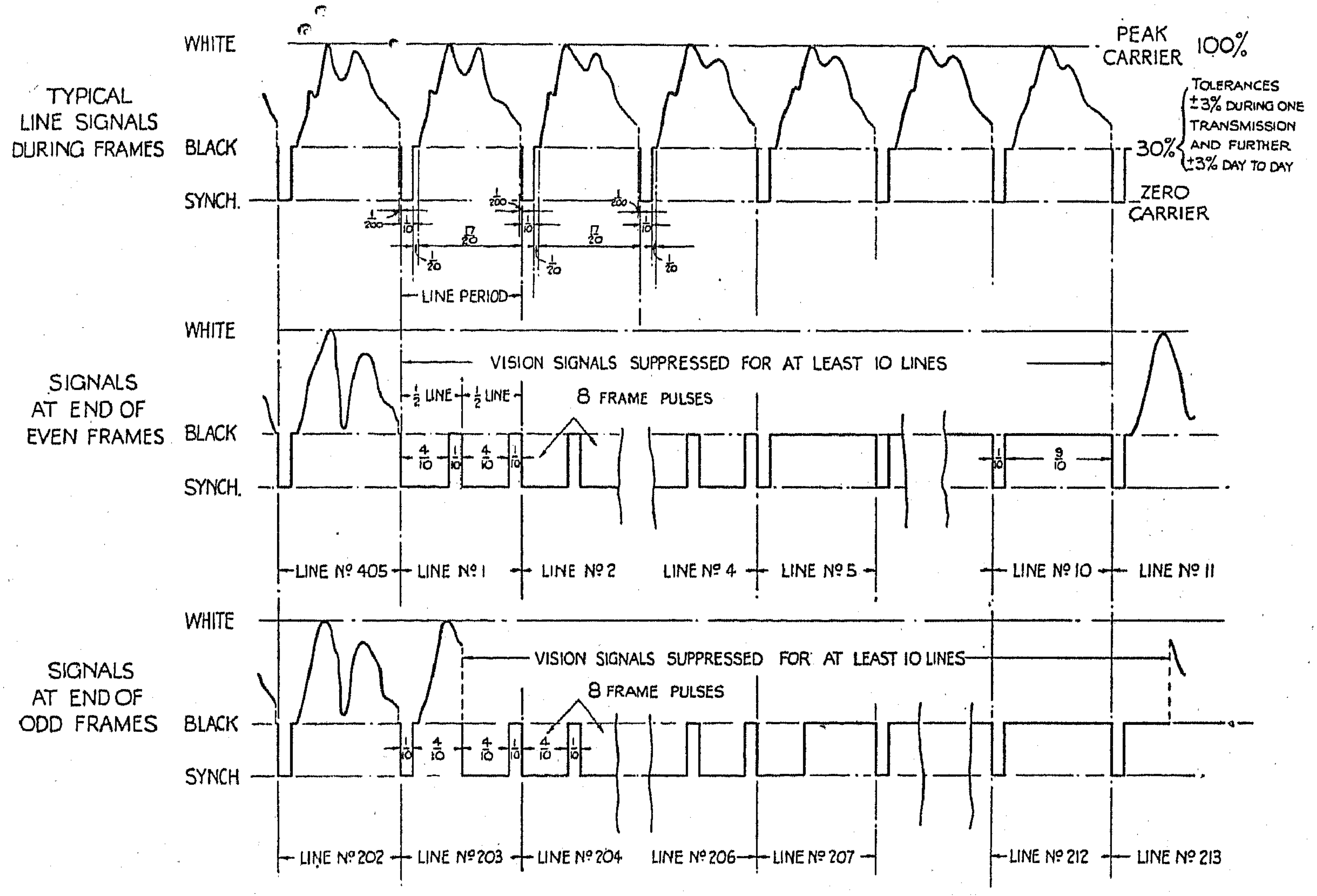

Fig. 1.—Marconi-E.M.I. television system: transmitted wave-form.

(f) Picture ratio.

The picture ratio will be 5 : 4, i.e. the distance scanned during the active 84·5 % of the total line period will be 5/4 times the distance scanned during the 192·5 active lines of the frame.

(g) D.C. modulation.

The picture-brightness component (or the d.c. modulation component) is transmitted as an amplitude modulation, so that a definite carrier value is associated with a definite brightness. This has been called "d.c. working," and results in there being no fixed value of average carrier, since the average carrier varies with picture brightness. The radio-frequency transmitter output is specified in what follows as a percentage of the peak output. This percentage is in terms of current (or voltage) and not in terms of power.

(h) Vision modulation.

The vision modulation is applied in such a direction that an increase in carrier represents an increase in picture brightness. Vision signals occupy values between 30 % and 100 % of peak carrier. The amount by which the transmitted carrier exceeds 30 % represents the brightness of the point being scanned.

(j) Synchronizing modulation.

Signals below 30 % of peak carrier represent synchronizing signals. All synchronizing signals are rectangular in shape and extend downwards from 30 % peak carrier to effective zero carrier.

(k) Line-synchronizing signals.

The line-synchronizing signals are of one-tenth of a line duration, and are followed by a minimum of one-twentieth of a line of black (30 % peak) signal.

(m) Frame-synchronizing signals.

The frame-synchronizing signals comprise a train of two pulses per line, each occupying four-tenths of a line and having one-tenth of a line interval of black (30 % peak) signal between them. At the end of even numbers of frames the first frame pulse starts, coincident with what would have been a line signal; and at the end of odd numbers of frames the first frame pulse starts half a line after the preceding line signal. Each frame signal consists of 8 pulses, occupying 4 lines. During the rest of the intervals between frames, normal line-synchronizing signals will be transmitted, with black (30 % peak) signals during the remaining nine-tenths of the line.

It will be noted that throughout the interval between frames (as during the whole transmission) the carrier falls from 30 % to zero regularly at line frequency and in phase with the beginning of the normal line-synchronizing pulses.

(n) Variations in transmitted wave-form.

The 15·5 % interval between vision signals of successive lines, and the 10 lines' interval between successive frames, are minimum intervals used at the transmitter. During the initial development of the transmitter certain transmissions may have longer intervals between lines and between frames, corresponding to the transmission of a black border round the picture.

The 30 % carrier is the "black level" below which no vision signals exist and above which no synchronizing signals extend. The mean black level of any transmission will be (30 % ± 3 %) of peak carrier. The black level during any one transmission will not vary by more than 3 % of peak carrier from the mean value of that transmission.

The residual carrier during the transmission of a synchronizing pulse will be less than 5 % of the peak carrier.

The line frequency and the frame frequency will be locked to the 50-cycle supply mains, and therefore will be subject to the frequency variations of the mains.

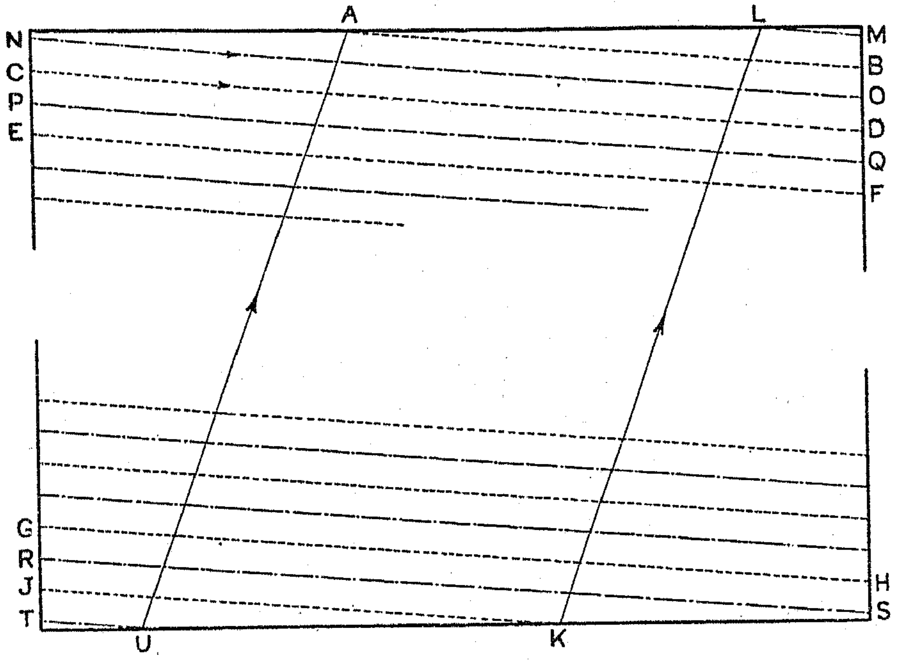

Fig. 2.—Diagram of interlaced scanning.

Explanation of Method of Interlacing

The method of interlacing is demonstrated in Fig. 2, which represents the top and bottom portions on the scanned area with the distance between the lines very much enlarged. The lines show the track of the scanning spot, which moves under the influence of a regular downward motion (frame scan) with quick return and a regular left-to-right motion (line scan) with very quick return (not shown in Fig. 2). The combination of these motions produces the slightly-sloping scanning lines. Starting at A, not necessarily at the beginning of a line, the spot completes the line AB, returns to the left and traverses line CD, then EF, and so on down the "dotted" lines on the drawing. At the bottom of the frame the spot travels along line GH and then starts at J and travels to K. At this point the return stroke of the frame motion begins, and returns the spot to L at the top of the frame. A complete frame-scan has now been made since leaving A, so that 202½ lines have been completed, and the point L is half a line away from A. The downward frame motion now starts again, causing the spot to travel along LM, completing a single line motion JKLM. The spot then returns to the left and traces out line NO, which, owing to L being half a line ahead of A, will lie between lines AB and CD. Similarly the next line (PQ) will lie halfway between CD and EF. The spot now traces down the chain-dotted lines to RS and finally traces out TU. At U the frame-return causes the spot to rise again to the top. When the spot reaches the top it will have completed 2 frames since leaving A, and as two frames occupy the time of exactly 405 complete lines the spot will return exactly to A, after which the cycle begins again.

From the foregoing it will be seen that the complete picture is scanned in two frames, but as each frame contains an integral number of lines, plus a half, the two frames will interlace. The system does not require the short return-times shown for the line and frame scans, nor need the lines begin in the positions shown. Provided the line and frame traversals are regularly recurrent and have the correct frequency ratio (2 frames = odd number of lines), an interlaced picture will be obtained.

PART II

VISION INPUT EQUIPMENT

By C. O. BROWNE, B.Sc.

(*First received* 1*st December,* 1937, *and in final form* 12*th March,* 1938.)

SUMMARY

Television equipment, in particular that supplied to the B.B.C. for the London Television Station, is described, and the technical considerations which led to its development are outlined. A description is given of the purpose and practical design of the apparatus handling modulation frequencies, which comprises studio equipment, camera control equipment, modulation amplifiers for the radio transmitter, and associated apparatus.

Owing to the large amount of equipment covered by these headings, little more than cursory descriptions can be included, making it imperative to omit many details of design. References are therefore made to the relevant patent specifications, from which more detailed information may be gathered.

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(1) INTRODUCTION

The specification of wave-form adopted by the Marconi-E.M.I. Television Co. includes a number of fundamental conditions which are basic, and which must be satisfied whatever the form of the television equipment. Apart from the question of the number of lines and frames, the equipment must be capable of meeting the demands of the d.c. system of transmission as defined in Part I of this paper.

The form of the television equipment is largely defined by the choice of a method of scanning the picture, and much experimental work had been done in the laboratories of Electric and Musical industries, Ltd., on both mechanical and electrical methods of scanning before the Emitron camera was eventually evolved. Although good pictures were obtained using Emitron cameras as early as 1934, the signals derived from these cameras possessed certain peculiarities not met with in mechanical scanning equipment. Considerable development work was necessary before these cameras could form part of equipment in which the basic desiderata of the wave-form specification are recognized. Once these difficulties had been overcome, it was possible to take advantage of the facilities and flexibility afforded by the Emitron cameras in laying down equipment for practicable transmission of television programmes.

A full-scale studio equipment answering the requirements for a television service was completed in the spring of 1935, and was, apart from a number of small improvements, essentially the same in fundamental design as the equipments installed at the London Television Station and in the mobile television scanning van which was subsequently constructed for outside broadcasts. A particular form of modulation amplifier was developed to meet the specific requirements of radiated power of the transmitter for the London Television Station.

(2) GENERAL LAYOUT

The extent of the studio and camera control apparatus was influenced considerably by the requirements of programme production, and the general layout of the equipment evolved is shown in schematic form in Fig. 3.

In order to provide flexibility for studio productions a number of cameras are required, giving the producer the facility to add variety to his camera viewing-points without actually moving the cameras. Six camera channels are provided, of which any two may be used in conjunction with two film projectors for the presentation of a continuous programme of film. The circuits of all the camera channels are identical and the channels are therefore interchangeable; an unquestionable advantage in circumstances of emergency caused by a breakdown.

It is necessary that the programme producer should be able to see not only the picture from the camera channel which is connected to the radio transmitter, but also the pictures scanned by any of the remaining five cameras. In order to curtail the extent of the control apparatus, a compromise is made, in that the camera fading is arranged after the " A " amplifiers, and the succeeding equipment required for producing pictures is constructed only in triplicate. The fading mixer is remotely controlled, and has three independent output circuits which lead to the three picture channels; one of these is connected to the line to the radio transmitter, and the other two are available for monitoring pictures from any of the remaining five camera channels.

A further requirement is that all cameras should be synchronized, so enabling the producer to fade from one picture to another without resorting to a change-over of synchronizing signals. An added advantage accrues from this arrangement in that two or more pictures may be superimposed if required. This demand necessitates that the scanning circuits of the cameras, and also the various pulses required for the development of the picture and synchronizing signals, should be timed from a master oscillator. It is preferable that the latter should, in turn, be controlled in frequency by the frequency of the supply mains. Summarizing, in the feeder from the control equipment to the radio transmitter there is a continuous train of synchronizing signals; and picture signals, originating in any of the camera channels, are inserted accurately in the appropriate intervals between synchronizing-signal pulses.

As the modulation amplifiers are closely associated with the radio transmitter they should perhaps be visualized as part of the transmitter equipment. The transmitter would in general be in a location remote from the camera control equipment (many miles in the case of a television outside broadcast), so that it was considered important that there should be one channel only connecting control equipment to modulation amplifiers. This channel should transmit television signals, which, apart from the relative amplitudes of the picture and synchronizing signals, should conform with the wave-form specification. The modulation amplifiers magnify these signals, preserving their d.c. characteristics, and modulate the carrier of the radio transmitter.

(3) STUDIO EQUIPMENT

Cameras

In order to leave as much free space as possible in the studio for the handling of scenery, lighting, and so on,

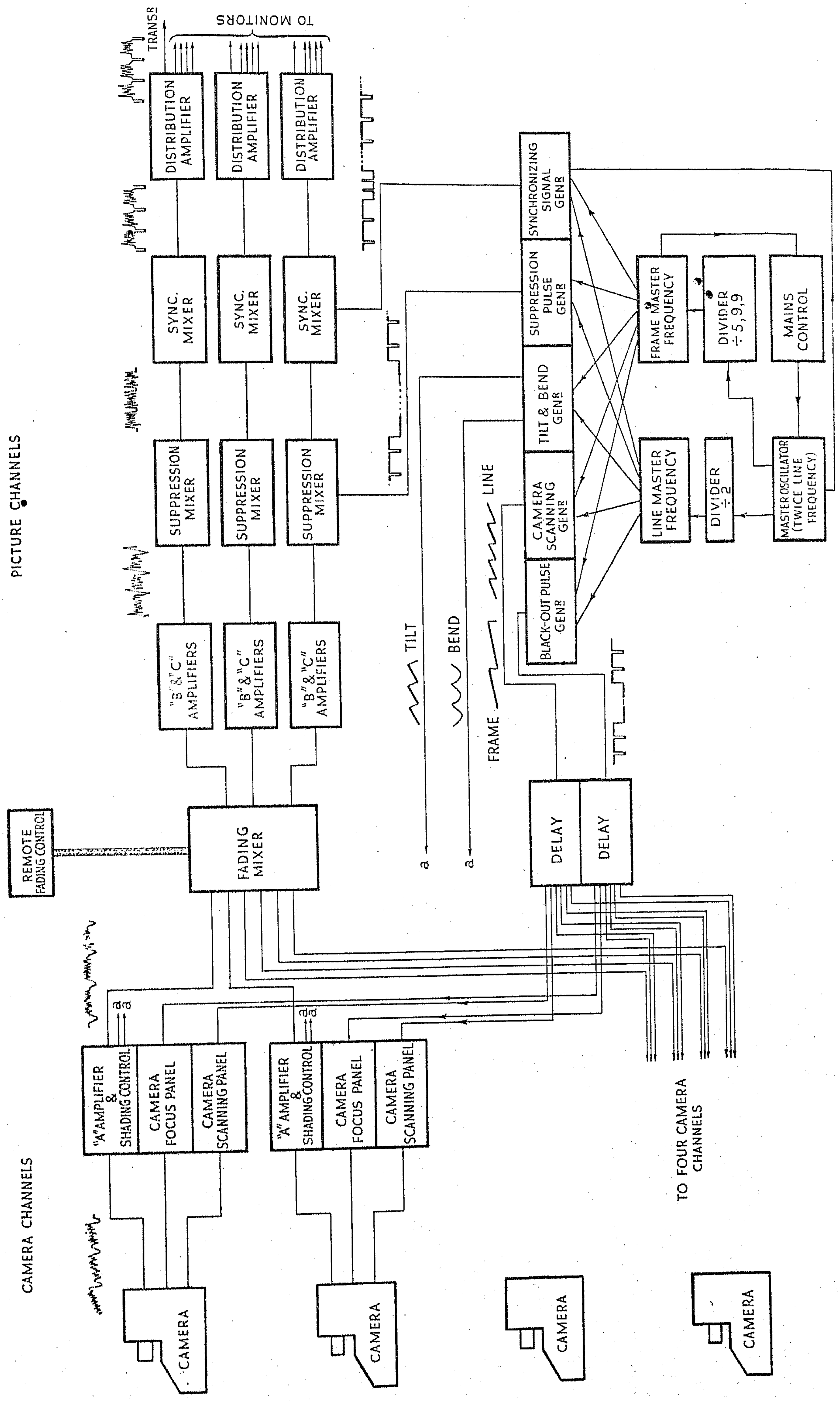

Fig. 3.—Schematic layout for control equipment of 6-camera and 3-picture channels.

each camera is designed as a unit to which the supplies are carried by a single cable from the camera control equipment, which would in general be housed exterior to the studio.

Each camera carries, apart from the Emitron tube itself, an optical system and view-finder, and a head amplifier. The optical system consists of a main lens which forms an image of the scene to be transmitted on the mosaic screen. Coupled to the main lens is a similar lens of the viewfinder which forms a duplicate image on a ground-glass screen having the same dimensions as the mosaic, and which is observed by the camera operator. Automatic compensation for parallax is provided so that the centre of the viewfinder image corresponds to the centre of the transmitted picture for all distances of the object in focus from close-up to infinity. The complete camera is shown in Fig. 4 (see Plate 1, facing page 80) with a pair of 12-in. telephoto lenses having a maximum aperture of $f/4 \cdot 5$. For general purposes two 6·5-in. $f/3$ lenses are used, this focal length being the shortest permitted by the construction of the Emitron tube itself. The width of the mosaic is 4·75 in., enabling a viewing angle of 40° to be subtended when the 6·5-in. lens is focused to infinity.

The head amplifier contains four valves; the grid of the first valve is connected to the signal plate of the Emitron tube, and is used as a cathode follower. (As the cathode follower is used frequently throughout both control equipment and modulation amplifiers, the advantages of this circuit have been made the subject of Appendix 1.) The cathode of the first valve is connected to the ring surrounding the signal-plate visible in Fig. 5 (Plate 1), so that its variations in potential are in phase with the potential-changes of the signal plate, and in consequence the capacitance of the input circuit is effectively reduced from 16 $\mu\mu$F (ring disconnected) to 12 $\mu\mu$F. The amplitude of picture signals as generated in the input circuit is made as high as possible relative to ground noise, by ascribing a large value to the input resistance, with subsequent compensation in the "A" amplifiers for the losses in higher frequencies involved.* The reduction in input capacitance enables a larger load-resistance to be used for the same amount of frequency correction. An additional boost of the lower frequencies, as generated by the Emitron tube, is also included in order to override irregularities introduced by valve flicker or microphonic noises generated when the camera is being handled. The second and third valves of the head amplifier serve to amplify the signals, and the last stage is another cathode-follower which feeds into a flexible feeder contained in the camera cable.

Camera Cable

In addition to the feeder mentioned above, the camera cable also contains a second flexible feeder, through which negative pulses at line and frame frequencies are applied to the grid of the Emitron tube to shut off the cathode-ray beam during the flyback intervals. Each feeder consists of a fine cadmium-bronze conductor crinkled so that it is approximately supported by point contact only from the surrounding gutta-percha tube, which in turn is covered by a braiding of copper wire. The crinkled construction is effective in reducing losses in the dielectric, and as the inner conductor is definitely located the capacitance per unit length is comparatively uniform. The remainder of the conductors in the cable (of which a connector is shown in Fig. 6, Plate 1) supply voltages for the head amplifier, potentials for the Emitron tube, and the sawtooth currents for the deflecting scanning-magnets surrounding the neck of the tube. Coverings of wire braid, rubber tape, and an overall coating of cord braid finish the camera cable, rendering it waterproof and substantially impervious to electrical interference.

(4) CAMERA CONTROL EQUIPMENT

The camera control equipment may be divided into four main groups, comprising camera channels, picture channels, pulse generators, and supply equipment. The descriptive matter which follows relating to the camera control equipment should be read with particular reference to Fig. 3, which indicates diagrammatically the progress of development of the television signals.

Each camera channel contains a unit for focusing the cathode-ray beam of the Emitron tube, by which the correct potentials may be adjusted for the electrodes. This unit also contains controls for adjusting the beam current for optimum working; a reflecting galvanometer facilitating this operation. A relay disconnects all dangerous voltages from the camera cable if for any reason the scanning currents should cease to flow, e.g. owing to the inadvertent breaking of a camera-cable connection. Another unit is included in each camera channel which accepts sawtooth signals from the pulse generator, and drives scanning currents at line and frame frequencies into the deflection coils in the camera. This unit has controls affecting the height and width of the scanned area, and for shifting the scanned area bodily.

Picture Signals

Apart from the distortions of the picture signals which are deliberately introduced in the head amplifier, the signals from the camera also contain spurious signals originating in the Emitron tube, of which the character depends largely upon the illumination of the scene being transmitted. These spurious signals occur during both forward and flyback periods at line and frame frequencies. The effect of the forward-period spurious signals is generally an overall "tilt" of the picture signals in a line or frame scan, or an overall "bend," or the effect may be a mixture of both "tilt" and "bend." Further, the "tilt" and "bend" may occur in either sense. The signals photographed in Fig. 7 (Plate 1) are typical of those produced by a scene situated in a field of very poor illumination; Fig 7(*a*) showing the signals received from the camera after magnification in the "A," "B," and "C" amplifiers.

Fortunately, under conditions of fair illumination, the "tilt" and "bend" signals conform to a shape which can be balanced by a simple means consisting of artificial shading signals manufactured in the group of pulse generators, of which the "tilt" and "bend" components can be adjusted both in amplitude and in sense by a small number of controls. Fig. 7(*b*) shows the picture signals after the introduction of artificial shading signals containing "tilt" and "bend" components.

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* See Reference (1).

In circumstances of poor illumination the spurious signals contain components which cannot be balanced by means of simple shading wave-forms, with the result that under these conditions the remnant of uncompensated spurious signals appear as white or dark patches in parts of the picture.

As the character of the spurious signals is likely to be different in the various camera channels, it is obviously necessary to provide independent shading controls. In each " A " amplifier, to which the picture signals from the appropriate camera are taken, four controls are therefore provided by which the amounts of artificial " tilt " and " bend " signals at both line and frame frequencies may be adjusted.

The spurious signals which occur in the flyback periods are of a more erratic nature, their shapes depending upon a variety of circumstances. Since the scanning currents are synchronized, however, these spurious signals may be suppressed, preparatory to the introduction of the synchronizing signals, in the same manner for all camera channels. It is convenient to remove them later on in the picture channels, and the description of the process involved is therefore included in the description of the picture channels under the heading " Interval Suppression."

Fading Mixer

The outputs of the camera channels are taken to a mixing unit of which the controls are remotely situated with the producer. The circuit of this unit provides that any of the six input signals may be faded at will to either of three output terminals connected to the picture channels. Groups of six variable-mu valves are incorporated having a common anode circuit to each group, and each camera channel is connected to a circuit containing the grids connected in parallel of one valve from each group. The valves are normally backed off, but are brought into an operating condition when the remote potentiometers are manipulated.

(5) PICTURE CHANNELS

The signals from the output of the fading mixer are amplified by a " B " amplifier having adjustable gain, with maximum voltage-magnification of 150 times, and a " C " amplifier with fixed magnification of 20 times. Couplings between stages in these amplifiers follow transmission-line practice, in that the capacitance of the anode circuit of one stage is separated from the capacitance of the following grid circuit by a series inductance.

Following the " C " amplifier, a unit is included in which the intervals between lines and frames are " cleaned up " in readiness for the introduction of the synchronizing signals. As described in Part I, the level during these intervals represents the dividing line between picture and synchronizing signals; so, besides introducing the cleaning-up process, the suppression mixer introduces the direct component into the picture signal.

D.C. Insertion

The insertion of the d.c. component into a train of picture signals implies that the signal corresponding to picture black is established at a definite potential. This condition may usually be achieved by a cumulative process from a series of recurrent signals corresponding to black. Negative picture signals (" white " signals are more negative than " black ") are impressed upon the grid of a valve through a series condenser with a leak to earth, and are of such amplitude that grid current flows at the black (positive) signals. The grid current progressively charges the condenser, until a state is reached in which the charge acquired is balanced by the discharge of the condenser by the resistance leak to earth.

As the negative picture signals from the output of the " C " amplifier still contain spurious signals between lines and frames, which may be variably more positive than those corresponding to picture black, the cumulative process outlined above will not establish a definite potential corresponding to black. The charging current for the condenser is therefore arranged to be derived, not from grid current, but from the anode of an auxiliary valve rectifier connected from the grid of the valve to earth. Pulses are applied to the grid of this rectifier which render it inoperative during the intervals between lines and frames, so that the picture-signal amplitudes are referenced from the " blackest " signal derived from the picture.* It will be appreciated that this arrangement is in some respects a compromise, because the blackest part of every picture will not invariably reflect the same (or zero) light, but it does ensure in addition that in the subsequent circuits the picture signals are handled without amplitude distortion, and without extending below " picture black " level into the region allocated for the excursions of the synchronizing signals.

Interval Suppression

The picture signals having been referenced from black, the spurious signals are suppressed by adding large positive pulses to the negative picture signals during the intervals between lines and frames.* The pulses lift the spurious signals clear of the picture signals in the infra-black direction, and the spurious signals are removed by rectification at a subsequent valve. This valve is provided with a bias control, by which the level at which the suppression pulses are cut off can be adjusted to be the same as that of picture black. Fig. 7(*c*) (Plate 1) shows picture signals to which this process has been applied.

Synchronizing-Signal Mixer

The picture signals are now free from spurious signals and contain a direct component. In the following unit the synchronizing signals are added to the " prepared " intervals between lines and frames, and appear as in Fig. 7(*d*). The television signals are now ready for radiation, except for the relative amplitudes of picture and synchronizing signals. It will be explained that, as the modulation amplifiers limit the amplitude of synchronizing signals, it is usual to maintain unity ratio between the amplitudes of synchronizing and picture signals from the control equipment.

Distribution

Each picture channel is terminated by a distribution amplifier from which five lines radiate. The circuit of this amplifier comprises cathode-follower valves of which the grids are fed in parallel with the picture signals; these valves feed the modulation amplifiers of the radio transmitter, monitoring points, etc.

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* See Reference (2).

(6) MASTER-FREQUENCY GENERATORS

The main requirements of the master-frequency generators are that there should be accurately $202\frac{1}{2}$ line-timing signals per frame-timing signal, and that the frame signals should be in synchronism with the supply mains (50 cycles per sec.). A master oscillator operating at twice line frequency (20 250 cycles per sec.) is provided, and its frequency is divided down by " counter " circuits to the frame frequency.* The master oscillator is of the multivibrator type, and is such that its frequency can be controlled to a limited extent by variation of the bias on one of the valves. The derived frame-frequency pulses are added to the sloping portion of sine waves taken from the mains, so that the instantaneous amplitude of the combined signals at the occurrence of frame pulses will vary if the latter tend to depart in phase from the mains. The amplitude variations are separated by a rectifier which provides bias for the master-oscillator circuit, thereby controlling the master frequency, so that, when divided, the frame frequency is equal to the frequency of the mains.

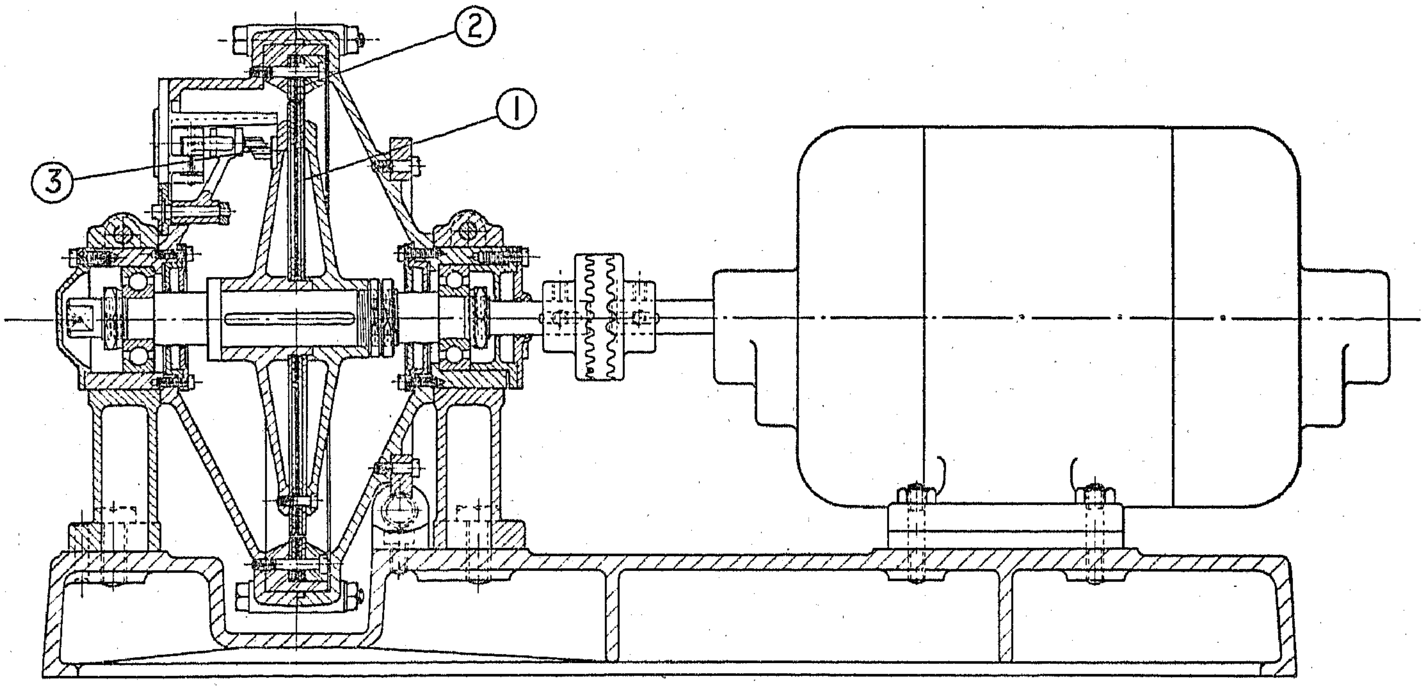

Fig. 8.—Master-frequency generator.

In the " counter " circuits referred to above, a condenser is included which is charged to an increasing potential by successive pulses, and the potential is arranged to be sufficient to " trigger " a multivibrator circuit, associated with the condenser, after a given number of pulses. The circuit immediately discharges the condenser to its initial state, and pulses are derived from the discharges which can then be divided in a further counter circuit, and so on. In the case of the line frequency it is only necessary to divide the master frequency by 2, but in order to obtain the frame frequency the master frequency is divided successively by 5, 9, and 9.

Mechanical Master-Frequency Generator

The action of the mains-frequency control circuit of the master oscillator is comparatively fast, and in consequence rapid changes of phase of the mains are reproduced in the television signals. Since these signals are all accurately inter-related, this is of no consequence when a cathode-ray receiver is being used, but a mechanical receiver possessing considerable inertia would be unable to follow quick changes in phase. As an alternative to the electrical oscillators, a mechanical master-frequency generator has therefore been used which generates a twice-line master frequency and frame frequency. This machine (shown in section in Fig. 8) is driven synchronously with the mains at 3 000 r.p.m. through a mechanical filter, and is of a capacitance-inductor type having 405 poles on both rotor (1) and stator (2), with a single pole (3) rigidly attached to the rotor for generating the frame-frequency timing pulse. In its construction the rotor was built up from laminations, all of which were cut simultaneously, and on assembly the laminations were rotated through an angle with respect to one another and bolted together. The same process was adopted in respect of the stator, and by this means repetitive errors, due to irregular spacing of the poles, have been reduced to a negligible quantity.

The master frequencies are fed to the units they control through adjustable delay circuits, in order that the various pulses shall be given the correct relative positions in the train of television signals. The time taken for signals to travel over a long length of camera cable is appreciable, and therefore a variable delay operated by a switch is provided by which the timing of the line-scanning currents can be adjusted to suit the length of cable in use. This switch also adjusts the heater currents of the camera-head amplifier, and the timing of the black-out pulses for the Emitron tube.

(7) PULSE AND WAVE-FORM GENERATORS

During the course of development of the television nals from the camera to the distribution amplifier, a variety of pulses and wave-forms are required which must be synchronized from the master frequencies. These artificial signals are derived from a group of "pulse generator" panels, which are required to supply "black-out" signals for the Emitron tube in the cameras and "suppression" pulses for removing spurious signals, and also to generate synchronizing signals. Each of these trains of signals is composed of pulses at line frequency, and in some cases pulses at frame frequency are introduced at the appropriate instant; multivibrator circuits being used for the generation of the pulses, which may be cleaned up by limiting the amplitude in both positive and negative senses.[*]

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* See Reference (3).

As it should be assumed that the receivers will rely on the accurate formation of synchronizing signals from the transmitter to enable good interlaced scanning to be obtained, considerable trouble has been taken to ensure that the timing of synchronizing signals is correct. The narrow pulses of the line-synchronizing signals and the broad pulses constituting a frame-synchronizing signal are applied respectively to the grids of two hexode valves; the latter being alternately switched into an operative condition by means of a control pulse of appropriate duration at frame frequency. An interlocking circuit involving further hexode valves is used to ensure that the change-over from line pulses to frame pulses is initiated by the simultaneous occurrence of an interval between broad pulses and a master frame-frequency pulse.[†]

It is convenient in the control equipment to have available a source of standard television signals, by means of which the levels of the transmitted signals may be set up. Suitable signals are produced by pulse generators, and constitute a black rectangular cross superimposed on a white background of peak amplitude; this artificial signal being mixed with the synchronizing signals in the picture channel. The wave-front of the vertical bar of the artificial signal as generated by the multivibrator circuits is comparatively sharp, and the reproduction of this wave-front on a receiver screen, or signal monitor, provides a good criterion of the efficiency by which the higher frequencies are being transmitted. An indication of the response at the lower frequencies of the system, or part of it, is afforded by the horizontal bar, while the d.c. conditions may be examined by noting any change in black level when the artificial signals are switched off.

Included in the pulse-generator group is a number of wave-form generators. Of these, one is necessary for the supply of the sawtooth signals at both line and frame frequency which are used to produce currents for the magnetic deflecting system of the Emitron tubes. As the gun in the Emitron tube is not normal to the plane of the mosaic, the area scanned on an imaginary plane perpendicular to the axis of the gun should have a keystone appearance: a condition which is achieved by modulating the amplitude of the line deflection by the frame deflection.[‡] But, in addition, a uniform angular velocity of the beam in the frame direction would produce an uneven separation of the lines on the mosaic, so that a further correction is introduced to compensate for the distortion which would otherwise be present due to this cause. Even so, by consideration of the solid geometry of the disposition of the elements in the Emitron tube it will be seen that the scanned area on the mosaic screen will be subject to "pincushion distortion." This is corrected in the camera itself by suitably designing the scanning coils so as to scan a rectilinear image on the plane of the mosaic.[*]

Other wave-form generators are wanted for the generation of "tilt" and "bend" signals at line and frame frequencies. The "tilt" signals are derived from the growth of potential of a condenser charged through a resistance; the condenser being discharged by appropriate pulses at line or frame frequency. The "bend" signals are obtained by an integration process of the "tilt" signals.[†] The outputs of both "tilt" and "bend" are symmetrical about earth, so that the control potentiometers on the "A" amplifiers have signals of opposite sense at each end, with a position of zero signal at the centre.

(8) FILM TRANSMITTERS

Two film transmitters are required in order that a continuous programme of film may be radiated if desired. These machines are standard theatre projectors as manufactured by the British Thomson-Houston Co. and are adapted to be used in conjunction with Emitron cameras with a suitable optical system and synchronous shutter. The projectors are of the intermittent type, in which the film is stationary in the gate for approximately 75 % of a complete picture-cycle ($\frac{1}{25}$ sec.), and a shutter driven by a synchronous motor is fitted, by which an image of the film is projected into the camera twice during the stationary period. The exposure of the mosaic occurs within the intervals between successive frames of the television signals, and the latent electrical image developed on the mosaic is scanned under conditions of no illumination. At the commencement of a transmission the phase of the master frame-frequency generator is adjusted to that of the shutter motors; the latter being left to run continuously during the transmission.

(9) SUPPLIES

To complete the description of the camera control equipment, some mention should be made of the supplies. Except for a small number of dry batteries which supply voltage only, mainly for control purposes, the equipment is entirely mains-operated. A number of separate high-tension rectifiers are used with independent smoothing circuits, and their outputs are stabilized by circuits which are an adaptation of the cathode-follower circuit (Appendix 1). Valves are provided in the cathode circuits of which the various loads are connected, and the required H.T. voltage is controlled by means of a battery connected between the grids of the stabilizing valves and earth. The stabilizers reduce the effective impedance of the H.T. supply in addition to diminishing irregularities and ripple from the rectifiers, and, because some variation in voltage persists due to fluctuations in mains voltage, additional circuits are included which amplify the fluctuations and re-introduce them into the grid circuits, so that the original variations tend to be neutralized.[‡]

The L.T. supplies are mainly alternating current, but where direct current is necessary, i.e. in the case of the head amplifiers, copper-oxide rectifiers and smoothing circuits are provided.

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[*] See Reference (4).

[†] *Ibid.*, (5).

[‡] *Ibid.*, (6).

[*] See Reference (7).

[†] *Ibid.*, (8).

[‡] *Ibid.*, (9).

(10) GENERAL CONSTRUCTION OF THE CAMERA CONTROL EQUIPMENT

All the units comprised in the control equipment are constructed in 19-in. panels, and fit into telephone racks of standard size. Considerable attention had to be paid to ventilation, in view of the large number of valves which are required (approximately 500, including rectifiers), and since it had been found that when amplifiers are worked under conditions of excessive temperature their characteristics vary considerably. In all units the valves are enclosed in a space immediately behind the front panel, otherwise devoid of components, so that when the units are mounted adjacent to one another in a rack a vertical passage is formed which is ventilated by a convection process. In some cases it has been advantageous to assist the ventilation by means of fans mounted at the top of the racks. The general form of construction and layout can be seen from Plate 2 (Fig. 9, camera delay panel; and Fig. 10, artificial-signal generator). These photographs show the back of the panels with the cover off. The panel nearest the observer is the sub-panel, the ventilating duct being between this sub-panel and the front panel.

In view of the possibility that cameras and camera control equipment might be operating in close proximity to the sound and vision aerials, where the field strength would be inordinately high, it was advisable to include radio-frequency rejector circuits, tuned to a frequency between sound and vision carriers, in the supplies to each unit where necessary. In addition, minute circuits, having low capacitance, were developed for the suppression of radio frequency at the grids of certain valves. The overall effect of the radio-frequency suppression is that a camera may be taken close to the aerials themselves, without traces of feed-back being apparent.

(11) PERFORMANCE OF THE STUDIO AND CONTROL EQUIPMENT

The maximum sensitivity of the equipment is limited by the ground noise from the amplifiers, and also by the shape of the " tilt " and " bend " spurious signals. With an average Emitron tube issued for programme service, satisfactory pictures can be obtained with an illumination of 130 foot-candles or 1 400 lux, and good pictures are easily obtainable with 200 foot-candles or 2 160 lux. This means that pictures can be transmitted in any reasonable condition of daylight; a dull day presenting about 200 foot-candles. Pictures can be obtained with as little illumination as 50 foot-candles, but would, of course, be somewhat marred by the defects mentioned above.

In order to meet the 2·5-Mc./sec. frequency and phase characteristics which a 405/50 system demands, each unit was designed to extend to a minimum of 3·5 Mc./sec., and on calibration was adjusted to have a maximum droop of 0·5 db. at this frequency. As there is a large number of units effectively in series, a maximum departure from a level characteristic of 0·1 db. was allowed before the unit commenced to cut off. In addition to the calibration of individual units an overall calibration of the equipment was made. This calibration would reveal traces of feed-back if the overall calibration was not that expected from the sum of the calibrations of individual units. Feed-back might be due to the physical disposition of components of the apparatus, but was usually indirectly due to the earthing system, which, owing to the quantity of apparatus involved, is inclined to assume long dimensions.

Tests were made on the " resolving power " of the equipment at the London Television Station by erecting screens on which a number of lines of known spacing were ruled at a given distance from a camera, and the result showed that 240 black lines separated by equal white spaces could be resolved when the whole width of the mosaic was in use. The standard of excellence of the focus of the cathode-ray beam of the Emitron tube is more than adequate, practical tests showing that the latest tubes are capable of resolving more than 1 000 lines.

Further tests were made on the efficiency of interlaced scanning by transmitting an inclined edge, and examining the monitor picture with an extended frame-scan. The results of these tests showed that each line contributes to the detail of the picture, and that the traces of the cathode ray on the mosaic of the Emitron transmitting tube were accurately interlaced.

(12) MODULATION AMPLIFIERS

General Requirements

It has already been pointed out that a single channel only connects the camera control equipment (which may be located either close to the radio transmitters, or remote in the case of an outside broadcast) with the modulation amplifiers of the radio transmitter. This channel carries television signals which are complete in themselves, in which a definite potential corresponds to the " black " level dividing-line between the picture and synchronizing signals, and it is the purpose of the modulation amplifiers to magnify these signals, preserving their d.c. characteristics, and to apply them to the grids of the final stage of the radio transmitter.

In Part I of this paper the point was stressed that the carrier should be reduced to zero during the transmission of synchronizing signals, and sufficient signal must therefore be applied to the transmitter to carry the grid potential beyond cut-off. The television signals applied to the input of the modulation amplifiers are usually adjusted as nearly as possible to contain equal amplitudes of picture and synchronizing signals, but owing to the curvature of the transmitter characteristic in the region approaching cut-off the radiated synchronizing signals are reduced in amplitude with respect to the picture signals.

The ratio of picture and synchronizing signals mentioned above is approximate only, because it is obvious that frequently the ratio may be disturbed by circumstances beyond the control of the operators of the equipment. Variations in synchronizing amplitude which might cause variations of black level would be likely in cases in which the signals were received over long lengths of cable or by radio link from the camera control equipment. Constancy of black level is a fundamental requirement of the system, and means are therefore provided, in the modulation amplifiers, by which the output

Plate 1

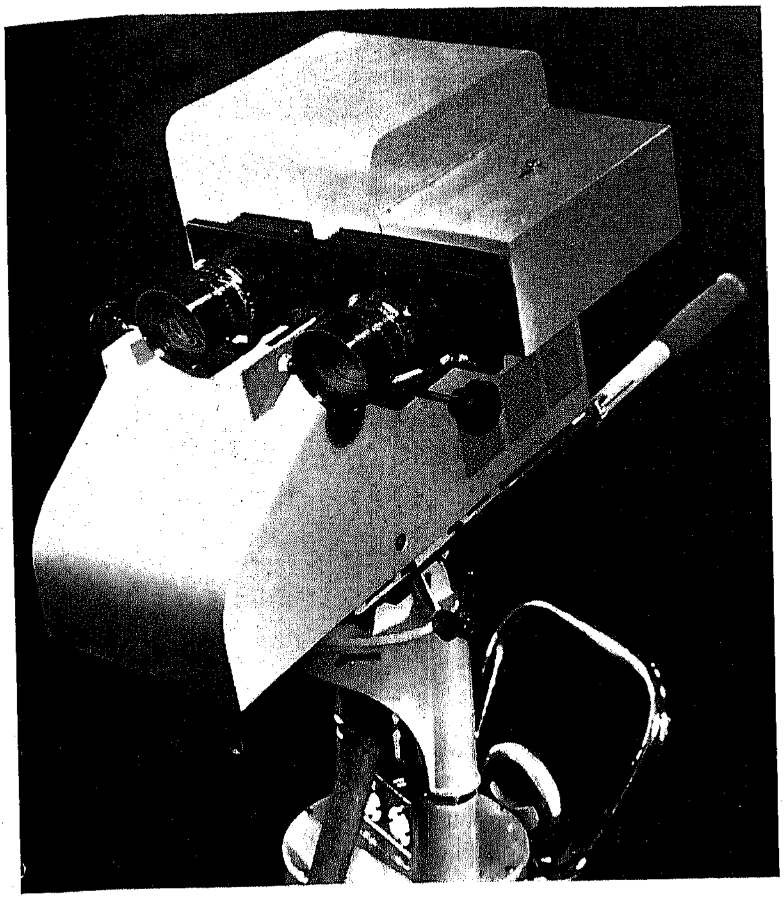

Fig. 4.—Emitron camera.

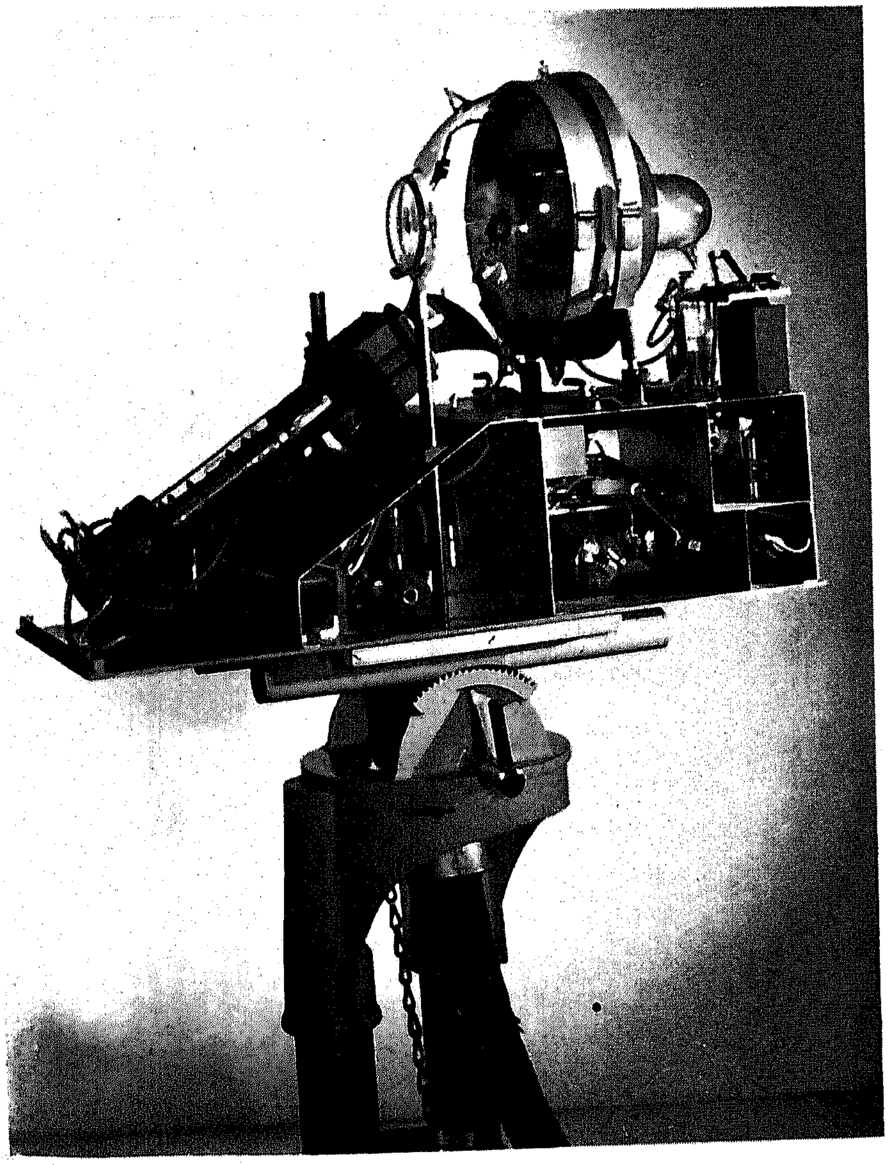

Fig. 5.—Emitron camera (cover removed).

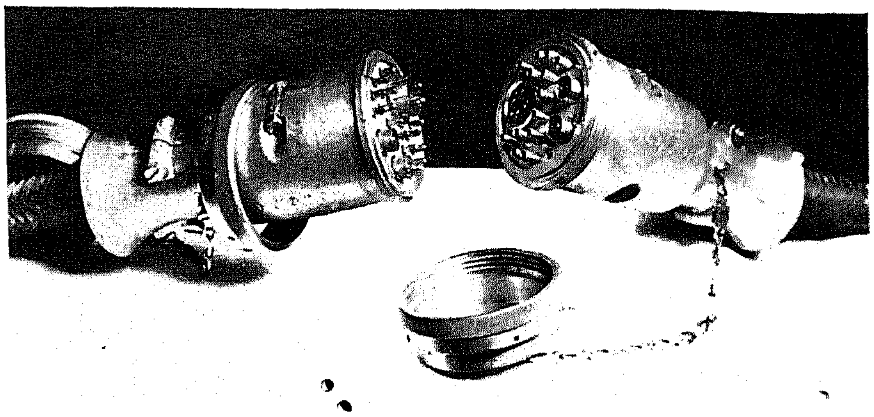

Fig. 6.—Camera-cable connector.

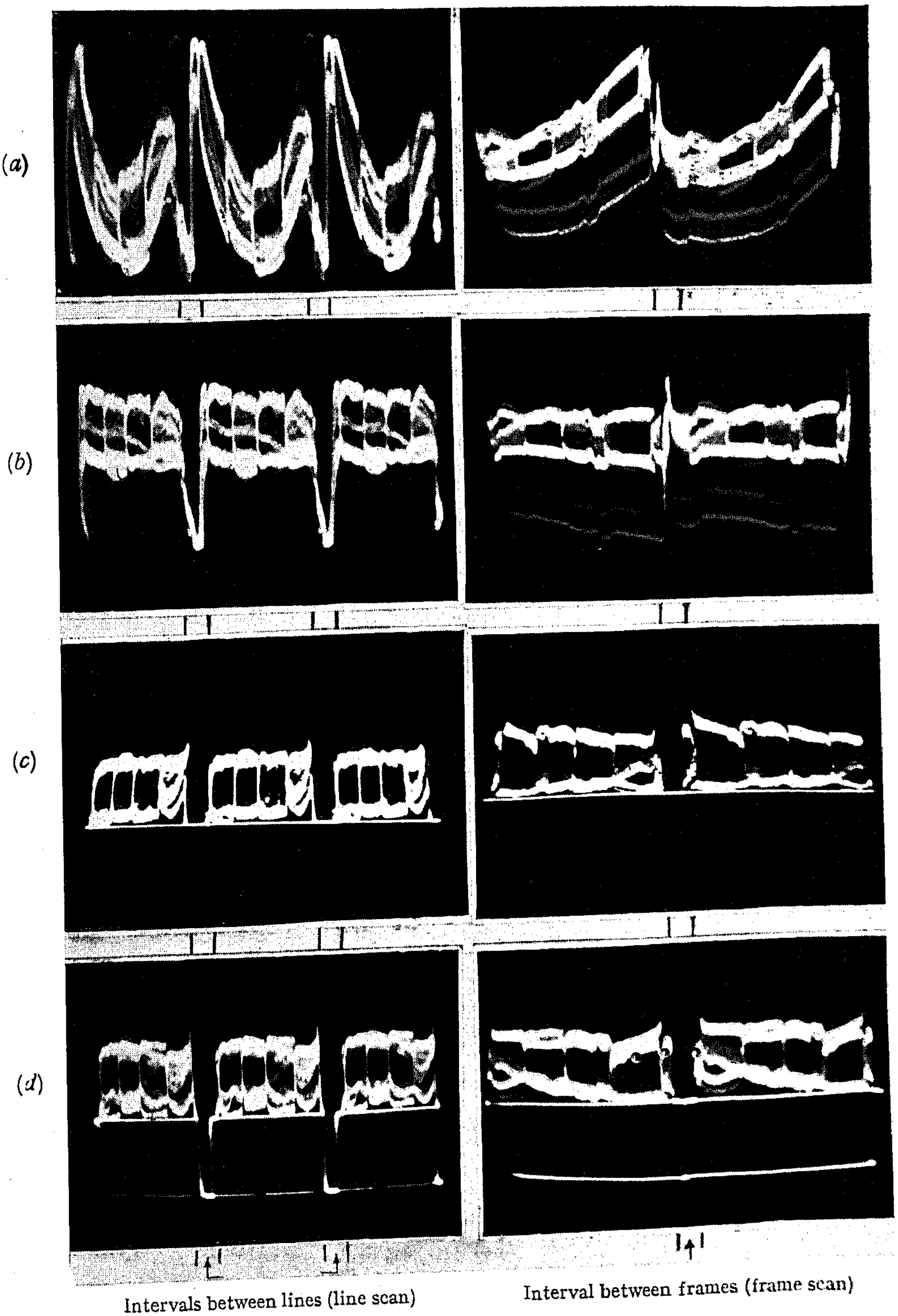

Fig. 7.—Development of television-signal wave-form.

Plate 2

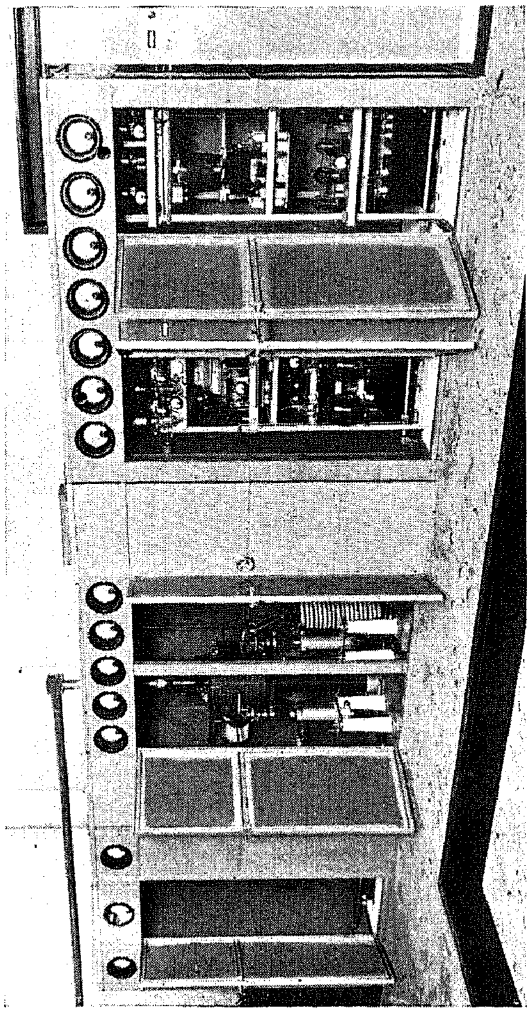

Fig. 14.—Modulation amplifiers.

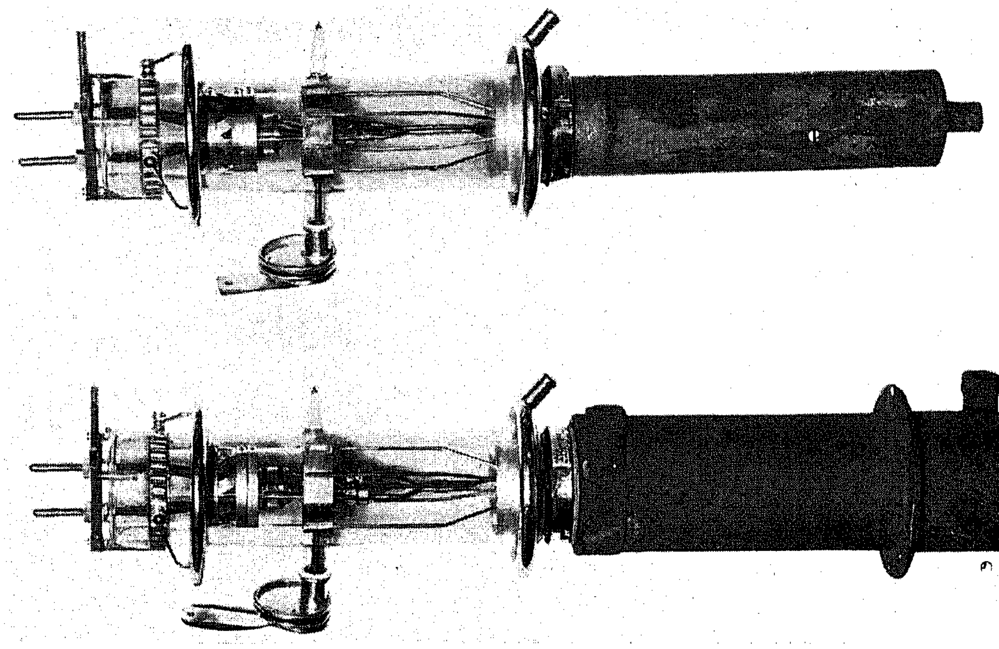

Fig. 21.—Transmitting valve, type C.A.T.9.

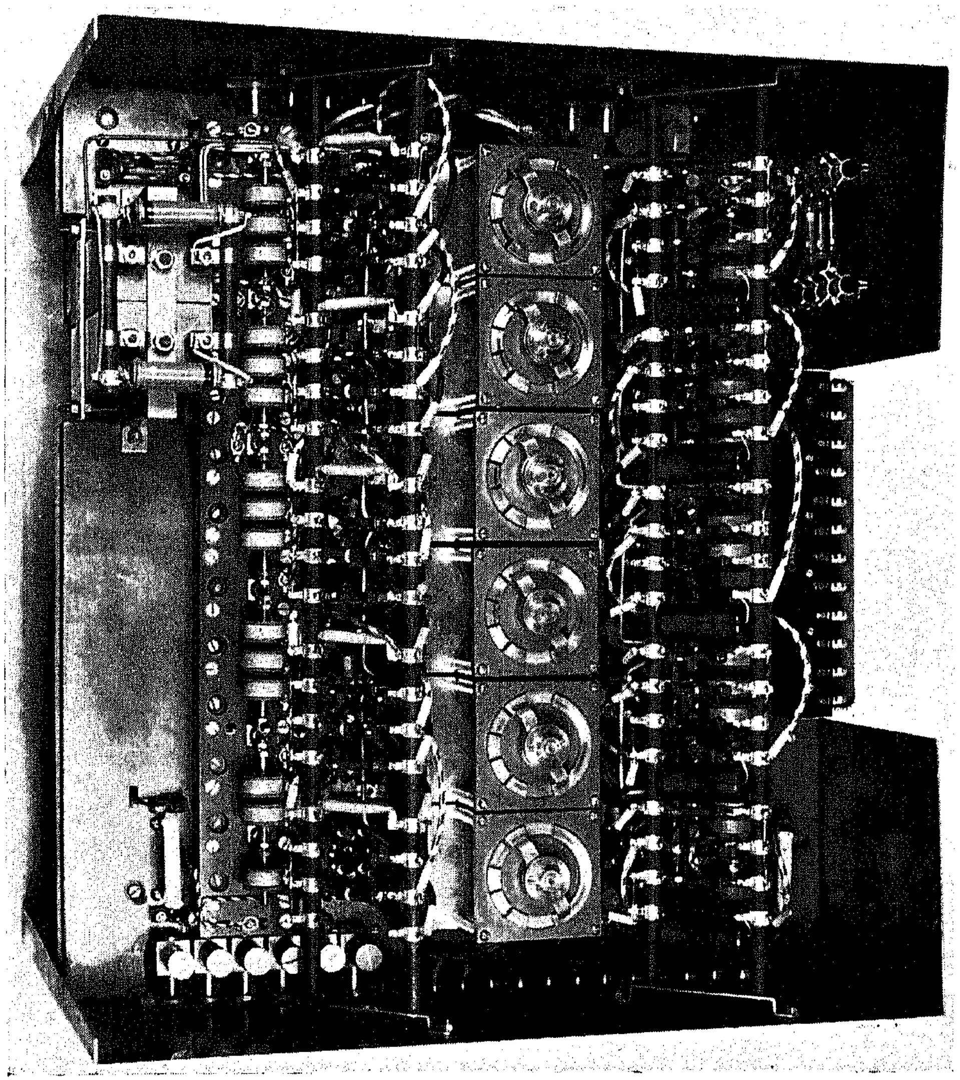

Fig. 9.—Camera delay panel.

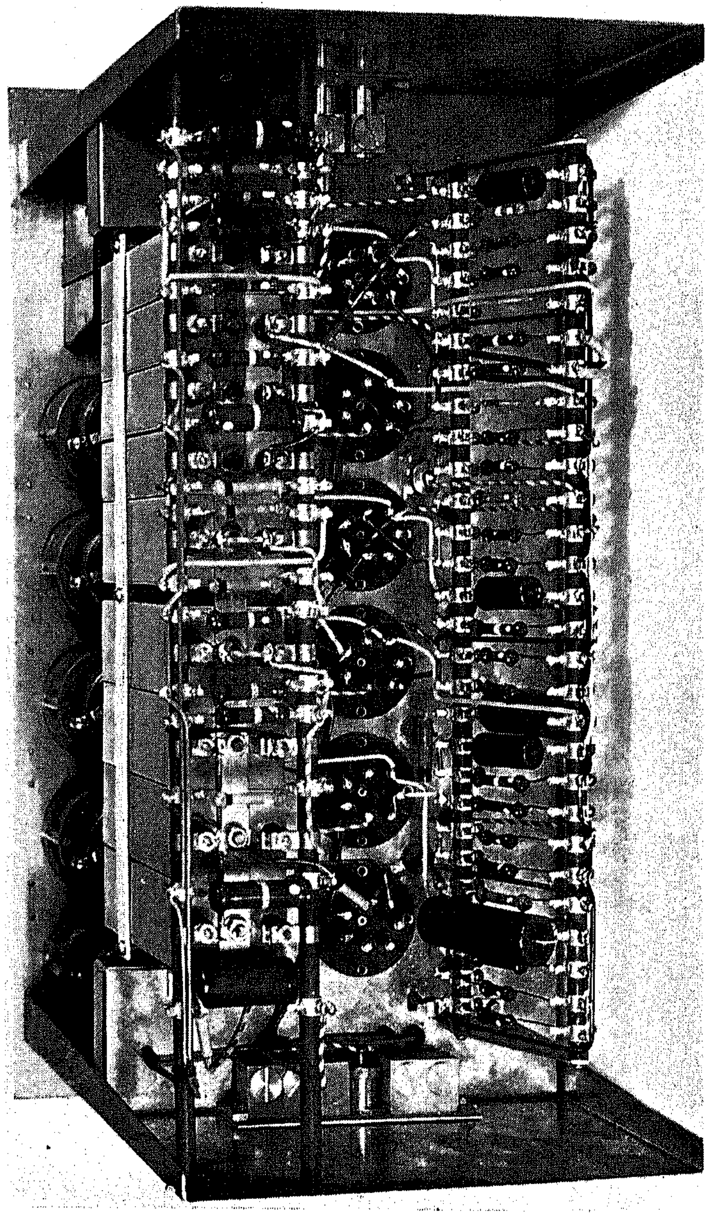

Fig. 10.—Artificial-signal generator.

potential corresponding to black level is automatically maintained at a predetermined value irrespective of considerable variations of the incoming synchronizing-signal amplitude.

In consequence, two controls are necessary to adjust the working conditions of the modulation amplifier, in order that the wave-form as radiated from the transmitter shall conform with the stipulation as to picture-signal/synchronizing-signal ratio. By means of the first of these controls the potential in the final circuit is adjusted so that black level produces 30 % of the voltage amplitude of carrier corresponding to peak picture; then the second control is operated by which the magnification of the amplifiers is adjusted until the transmitter is adequately modulated.

Other requirements of modulator amplifiers may be summarized as follows:—

(i) The final stage of the radio transmitter is grid-modulated, and requires a complete excursion of approximately 2 000 volts to cut off the carrier at one extreme, and to produce maximum carrier at the other. As the signals from the control equipment are transmitted with a minimum amplitude-difference of 10 volts (overall) from tips of synchronizing signals to peak of picture signals, the voltage magnification of the modulator amplifiers must be of the order of 200 times.

(ii) The amplitudes of the picture and synchronizing signals applied to the radio transmitter are approximately equal, so that the amplifiers are called upon to change the potential of the transmitter grids by 1 000 volts in the maximum period of 0·2 microsec. demanded by the picture detail of the system. The input capacitance of the transmitter, including the connecting line from the modulators, is about 400 $\mu\mu$F, so that the final stage of the modulators must be capable of delivering at least 2 amperes to charge the input capacitance over the amplitude range occupied by picture signals.

(iii) In order to radiate a signal in which the d.c. components are preserved, it is necessary that, after having charged the input capacitance to a given potential, the modulators should be capable of maintaining this potential indefinitely. The preceding condition, together with this stipulation, at once determines the power-handling capacity of the final stage of the modulation amplifiers. In addition, it becomes obvious that special attention has to be paid to the amplifier design, including the H.T. supply circuits, in order that there shall be no falling-away of potential over an extended period.

In a 405/50 television system the picture-element frequency is approximately 2·5 Mc./sec., and the modulation amplifiers are therefore designed to transmit a level characteristic up to this frequency. In order to prevent violent phase-changes towards the cut-off of the amplifiers, the frequency characteristic was designed to fade away gradually after 2·5 Mc./sec., and at 3·5 Mc./sec. is actually approximately 2 db. down. This frequency range introduces many problems into the design of the amplifiers; making it essential that the capacitances of components situated at vulnerable positions in the circuits be kept to a minimum.

In the design of amplifiers handling frequencies in the audible range only, the impedances of the H.T. and other supply circuits can usually be neglected at all but the lower audible frequencies; the latter being largely determined by economic considerations. It will be appreciated, however, that in the present case, at the other extreme, it is essential to transmit very low and zero frequencies, so that the properties of smoothing circuits of the rectifiers, from which the amplifiers are supplied, will in general contribute towards the overall frequency-response of the amplifiers. In consequence, it is a further requirement of design that the impedance of the smoothing circuits should be effectively constant over the range of modulation frequencies.

The requirements that the capacitance should be kept low in order to enable the apparatus to transmit the higher frequencies, and that smoothing circuits should be built out to constant impedance (Appendix 3), introduce difficulties into the design of the amplifiers, especially as constant-impedance networks assume considerably larger dimensions than the more usual form of smoothing circuit.

A supply of higher frequency than the 50-cycle mains largely provides a solution to these problems, because smaller values of inductance and capacitance are required in the smoothing circuits for the same effective smoothing, and the higher supply frequency allows smaller transformers, having reduced capacitances between windings, to be designed. In view of these considerations it was decided to incorporate a 50/500 frequency-changer set having a capacity of 50 kVA. It consists of four machines directly coupled in line, running at 750 r.p.m., and comprises a synchronous motor, inductor-type single-phase alternator, motor exciter, and alternator exciter.

(13) LAYOUT AND DESIGN

The circuits of the modulation amplifiers are shown in schematic form in Fig. 11, which also shows the points at which monitoring facilities are available. The equipment is composed of four amplifiers connected in cascade, which are capable of handling signals of progressively increasing amplitude; their circuits being essentially similar. Each consists of an amplifier stage followed by a cathode-follower, which provides a sufficiently low impedance to withstand the total effective input capacity of the succeeding amplifier. This capacity includes that of a "hold-off" voltage source, of which the potential is chosen to break down the voltage at the cathode of the follower stage to a value suitable for biasing the next amplifying valve. The operating conditions of amplifier and follower stages are chosen in such a way that the anode feeds are approximately in balance, so that the load upon the H.T. supply is nearly constant.* The remnant of unbalanced modulation-frequency current circulating in the H.T. rectifier smoothing circuits makes it necessary to build these out to an impedance which is constant at all frequencies.

Line Amplifier

The first of these amplifiers, the line amplifier, accepts positive signals from the control equipment at approximately 10 volts (double-amplitude peak) with a constant black-level potential of 10 volts. The signals are applied to the grids of the amplifier valve through a variable potentiometer K_1, of which the lower end is returned to

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* See Reference (10).

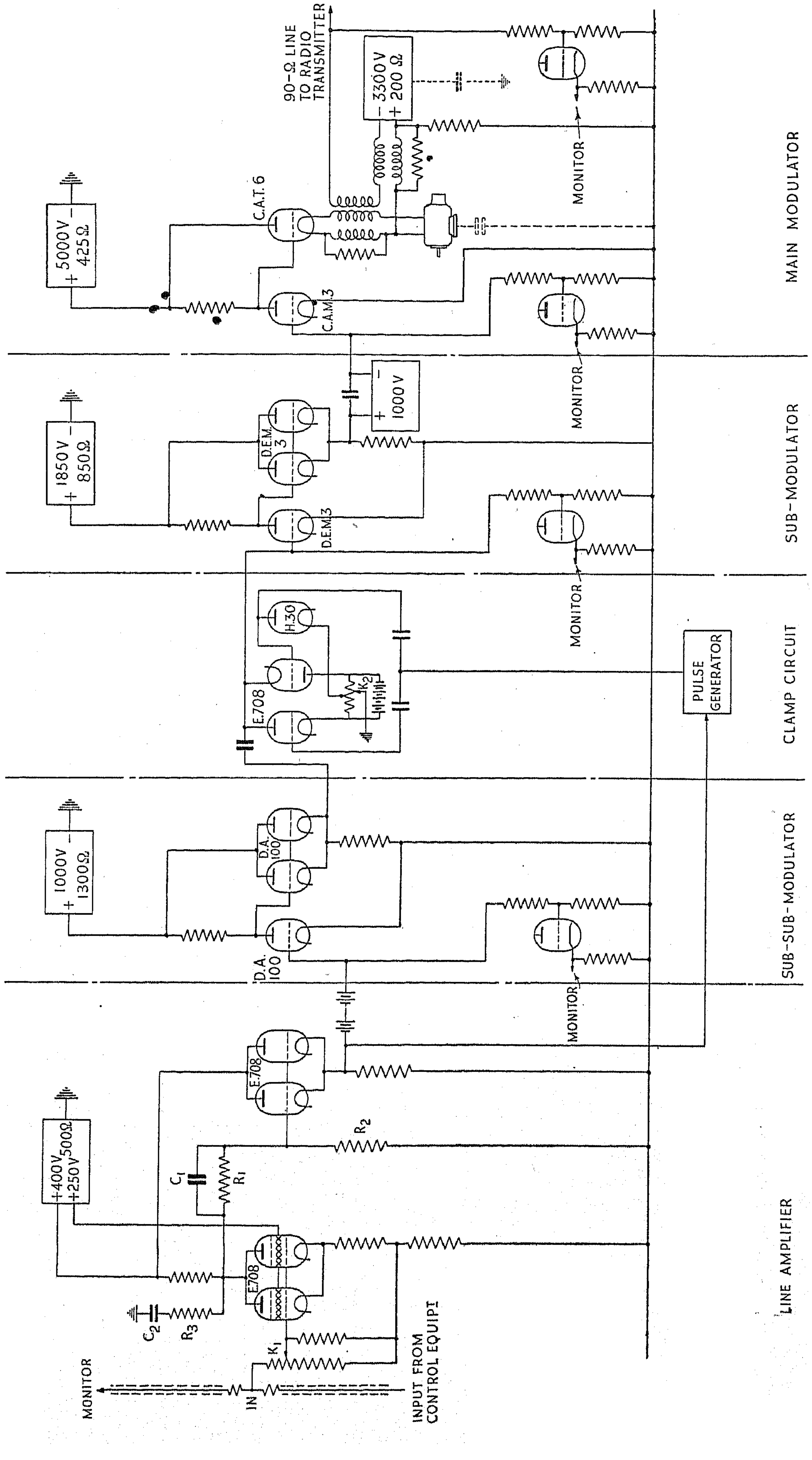

Fig. 11.—Schematic diagram of modulation amplifiers,

a point in the cathode resistance at which the steady potential is + 10 volts. This arrangement enables the amplitude control to be worked without upsetting the black-level potential at the grids of the valves.

The amplifier valves are direct-coupled to the grids of the follower stage via a potentiometer consisting of resistances R_1 and R_2, which ensure that the correct operating conditions obtain for the follower valves. In order to prevent attenuation of the higher frequencies due to the grid capacitance of the follower valves, the resistance R_1 is shunted by a condenser C_1, and the step in the frequency characteristic, introduced when the impedance of C_1 ceases to be small compared with R_1, is compensated by the circuit C_2R_3.*

A battery is included in the direct coupling between the line and sub-sub-modulation amplifiers, of which the voltage is chosen to establish the correct working conditions for the D.A.100 amplifier stage. The capacitance of the battery to earth presents an impedance which is variable with frequency in shunt with the cathode load, and its capacitance is therefore arranged to form part of a constant-impedance network (Appendix 2).

Sub-Sub-Modulation Amplifier

The circuit of the sub-sub-modulator is somewhat simpler in detail than that of the line amplifier, because operating conditions of the two stages are possible such that a direct connection can be made between amplifier and follower valves without resorting to a potentiometer coupling circuit. H.T. supply is provided by a double-wave rectifier circuit employing four U.6 valves, fed by the 500-cycle generator.

Black-Level Stabilization

In the specification of the radiated television-signal wave-form, the amplitude of black level is 30 % of the peak output which represents white in the picture. In view of the small tolerance of ± 3 % allowable for black-level variations, it is necessary to dispense with a direct coupling between the sub-sub-modulating amplifier and the sub-modulation amplifier, and to insert a coupling which holds the potential of the input grid corresponding to black level to a definite value.

A black-level region, free from picture signals and lasting for a minimum of 5 microsec. following the synchronizing signals, is included in the wave-form specification, and auxiliary positive pulses (derived from the synchronizing signals) are used to switch on the two E.708 valves which charge or discharge the coupling condenser between the two amplifiers, so that a fixed potential is established at the grid of the sub-modulator during these 5-microsec. periods.† The black level is therefore "clamped" at regular intervals of approximately 100 microsec. (1 line-period), and as the "clamp" circuit is conductive in both directions no leak is necessary for the coupling condenser. The precise potential to which the grid is switched is made adjustable with a potentiometer K_2 (Fig. 11) on the station control desk, and is used to set the black-level amplitude of the radiated signal.

Sub-Modulation Amplifier

A D.E.M.3 valve is used in the amplifier stage of the sub-modulation amplifier, which works into two D.E.M.3's in parallel in the cathode-follower stage. The H.T. supply is derived from a double-wave rectifier circuit using two M.R.7A valves; the power being obtained from the 500-cycle supply.

Variations in the values of the anode and cathode resistances would not only disturb the frequency characteristic of the system but would also upset the steady operating conditions of the succeeding stages. Furthermore, the capacitance to earth of these resistances is of considerable importance. After consideration had been given to the various forms which these resistances could take, a non-inductive wire-wound construction was adopted. The resistances themselves are mounted in a duct made from insulating materials, through which a current of air at low pressure is passed.

The coupling between the sub-modulator and the main modulation amplifier contains a rectifier circuit, which develops sufficient potential to "hold off" the voltage of the D.E.M.3 cathodes from the grid of the succeeding amplifier valve. Precautions are necessary to ensure that the capacitance to earth of this hold-off rectifier is kept as low as possible; the 500-cycle supply allowing a transformer to be designed with large clearances between primary and secondary, yet retaining reasonable overall dimensions. Even so, it was found necessary to build out this capacitance to a constant-resistance circuit, as described in Appendix 2. The television signals are negative at this point, and the hold-off rectifier is shunted by a large condenser which acts as a reservoir, so that no appreciable change of grid potential occurs due to the flow of grid current in the succeeding valve during the transmission of synchronizing signals.

Main Modulator Stage

The general arrangement of the main modulator stage is shown in Fig. 12. This indicates the layout of components but does not include the hold-off supply rectifier, which is situated in an adjacent cubicle.

A C.A.M.3 valve (1) is used in the amplifier stage and is directly coupled to a C.A.T.6 valve (2) used in the cathode-follower circuit. Complications are introduced in the output circuit, however, by the provision for filament heating, and by the large dimensions (and therefore large capacitance to earth) of the hold-off supply.

The cathode output circuit of the modulation amplifier is connected to the grids of the output stage of the radio transmitter through the hold-off voltage supply, and as considerable grid current flows during peak picture-signals the effective impedance of this supply must be made sufficiently low. In addition to the rectifier circuit, therefore, a cathode-follower stabilizing circuit is included, and the control voltage for it is derived from an auxiliary rectifier. By taking advantage of the 500-cycle supply the capacitance to earth of the hold-off unit was kept down to 400 $\mu\mu$F including transformer capacitances, and has subsequently been trimmed to 532 $\mu\mu$F to suit the series inductance.

The hold-off unit also contains the C.A.T.6 cathode resistance, and the capacitance of the unit is built out

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* See Reference (11).

† *Ibid.*, (12).

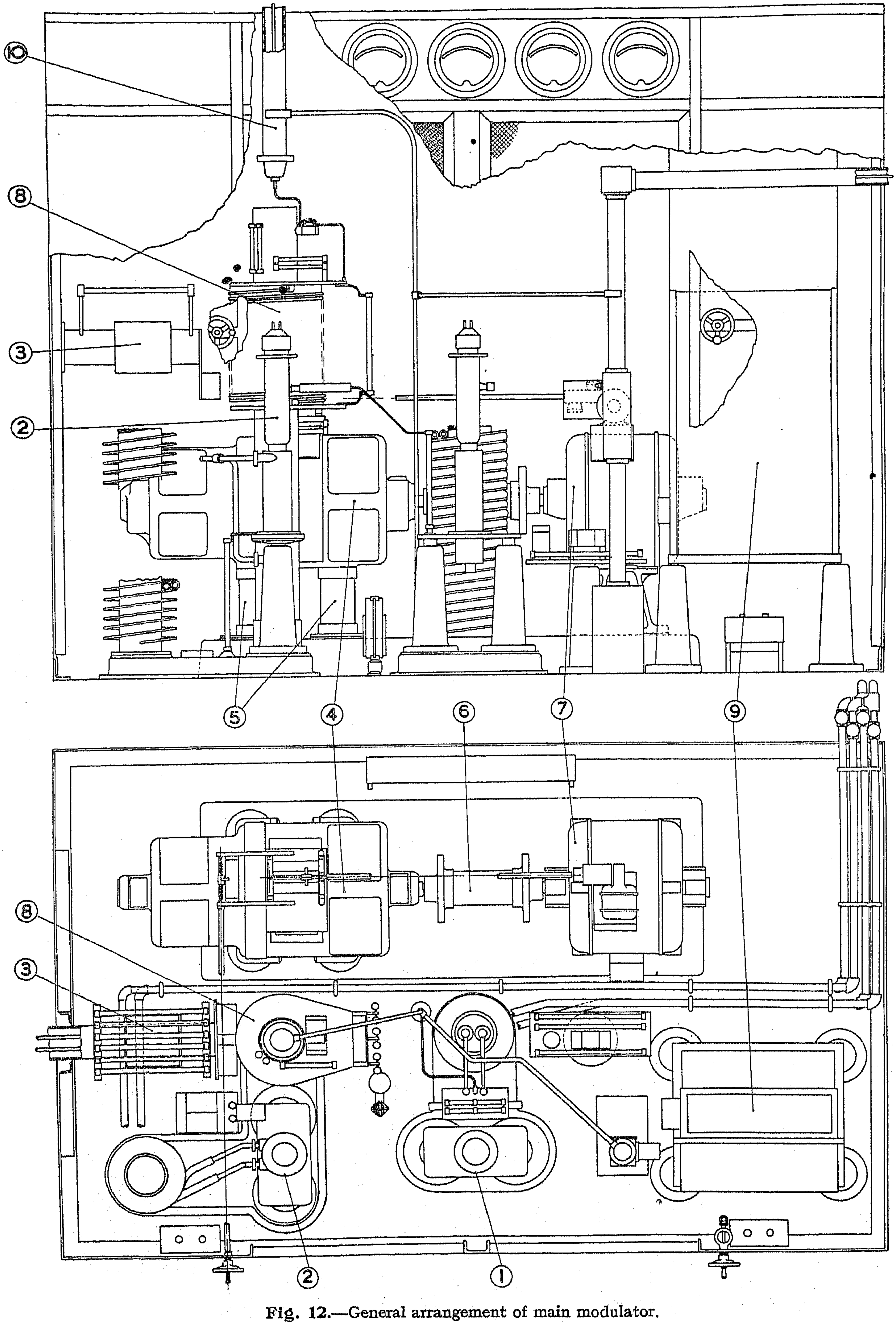

Fig. 12.—General arrangement of main modulator.

with a double-wound inductance (3) to appear as a constant impedance between earth and the filament-heating generator for the C.A.T.6 valve. This generator (4) is situated in the main-modulator cubicle, and is isolated from earth by supporting pillars of insulating material (5) and an insulated coupling (6) to the motor (7). Its capacitance to earth is 75 $\mu\mu$F, and is incorporated in a constant-impedance network which includes a triple-wound inductance (8) and the constant impedance presented by the hold-off circuit. The main features of this output circuit are indicated in Fig. 11, and further details are contained in Appendix 2.

Two of the windings of the inductance for the generator constant-impedance network consist of helices of copper rod of sufficient copper section to carry the filament current. In preference to making adjustments to the value of this inductance during calibration, it was intentionally made slightly larger than the value required by calculation, and a small variable trimming condenser was incorporated to pad up the capacitance of the filament generator to earth.

The same requirements obtain for the anode (9) and cathode resistances for the main modulator as for those in the sub-modulation amplifier, except, of course, that those associated with the C.A.M.3 and C.A.T.6 valves should be capable of dissipating more power. These resistances consist of asbestos woven mats enclosed in air ducts fabricated from insulating material, through which a current of air passes at low pressure. They will handle the 4-kW peak in the anode resistance or the 12-kW peak in the cathode resistance, with negligible change in the value of the resistance.

A mercury-pool rectifier is employed in a double-wave rectifier circuit for the H.T. supply for the main modulation amplifiers. The rectifier itself is of the glass-bulb variety, containing two anodes and a common cathode, the arc being struck by means of magnetically-operated auxiliary electrodes. Mercury-pool rectifiers possess a particular advantage when used in conjunction with constant-impedance smoothing networks, in that the resistance in the conducting state is very low.

The output of the modulation amplifiers is connected to the grids of the output stage of the radio transmitter through a concentric feeder (Item 10, Fig. 12) which is designed to withstand the 2 000 volts of modulation signals.

Monitoring Facilities

In order to maintain a check upon the operation of the amplifiers, potentiometers are included at selected points, by means of which signals at 10 volts amplitude are transmitted by local cathode-followers to the control desk through 150-ohm feeders. A direct-coupled amplifier is incorporated in the control desk, so that accurate comparisons may be made on a cathode-ray tube of the signal shapes, including d.c. level, at the monitoring points. In addition to the points shown in Fig. 11, a diode rectifier and a cathode-follower valve are attached to the feeder to the aerial, to provide a check upon the transmitted wave-form.

500-Cycle Alternator Load Distribution

In order to reduce the interaction between the various loads supplied by the alternator due to its regulation, the distribution network shown in Fig. 13 is used.* The regulation is mainly inductive and is composed of the inductive reactance of the armature and the armature reaction; the latter is made small by working the machine with a field which is nearly saturated. Tapped chokes are included in the load-distributing circuits, of which the first splits the load of the mercury-pool rectifier from the remainder of the loads. The mutual inductance between the two windings is equal to the equivalent inductance of the alternator, so that the voltage-drop across the alternator, due to the load of the mercury pool, will be effectively replaced for the complementary load. This process of load-splitting is repeated for each load on the machine; the mutual inductance being adjusted to equal the total inductance preceding the coil in question. With this arrangement there is virtually no transmission path from one load to another. At normal full load, however, the chokes are not magnetized, so that there is no general increase of regulation or loss of kVA.

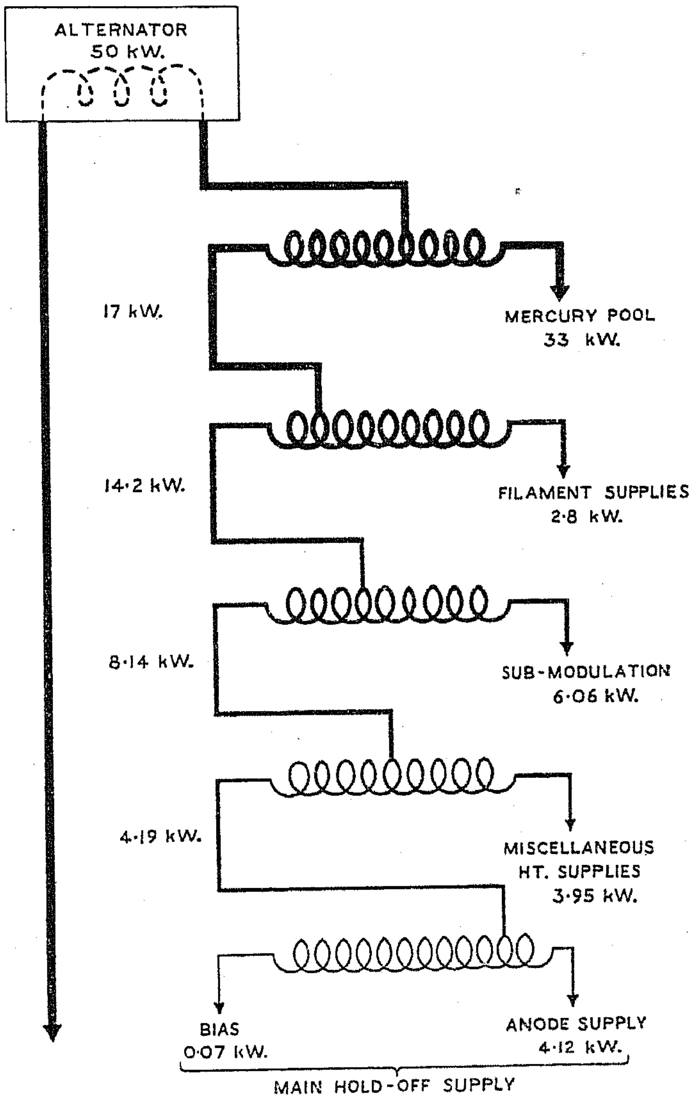

Fig. 13

Control and Interlock

The 500-cycle frequency-changer set and pumps for water cooling are hand-started, after which the modulation amplifiers can be operated from the control desk. A series of push buttons are provided of which the sequence of operation is determined by an automatic motor-driven selector. The push buttons themselves are interlocked to one another, so that switching-on of the various units can only be performed in the correct order. Failure of any part of the circuit operating an interlock will automatically prevent further damage to other parts of the system. Raise-lower controls are provided for the 500-cycle voltage-adjustment and filament motor-generator sets; remote meters fitted to the control desk facilitate the adjustment to valve feeds, filament voltages, etc.

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* See Reference (13).

Safety Precautions

The amplifier cubicles are arranged in line as shown in Fig. 14 (Plate 2), and a shaft running the length of the cubicles interlocks the gates with a main-supply trip and earthing switches. The shaft is operated by means of a handle at one end, and is arranged so that dangerous voltages cannot be applied until the gates are shut. Conversely, the gates cannot be opened until the dangerous voltages have been switched off and the high-voltage conductors have been earthed.

(14) CALIBRATION AND PERFORMANCE

Calibration and adjustment of the amplifiers involved three processes. The first requirement was the measurement of the component circuits which form portions of each amplifier stage, and the adjustment of the constant-impedance networks, of which there are a considerable number. A discrepancy in the results obtained from any one of these subsidiary circuits might well have given rise to endless searching for a variation of the overall frequency characteristic from that expected from calculation. In the second process the amplifiers themselves were adjusted and a frequency calibration was made. The final process involved measurement of an overall frequency-characteristic (Fig. 15) of the amplifiers; any divergence of the final calibration from that expected from the sum of the characteristics of the constituent units indicated the presence of feed-back. In the latter connection, considerable care had to be paid to the design of connecting wires and earth-return circuits, for a connecting wire only a few feet long may present appreciable reactance within the range of modulation frequencies. Included also in the final tests was the comparison of rectangular pulses as transmitted by the amplifiers with those applied to the input terminals; a test which immediately provided a very fair indication of the performance of the equipment.

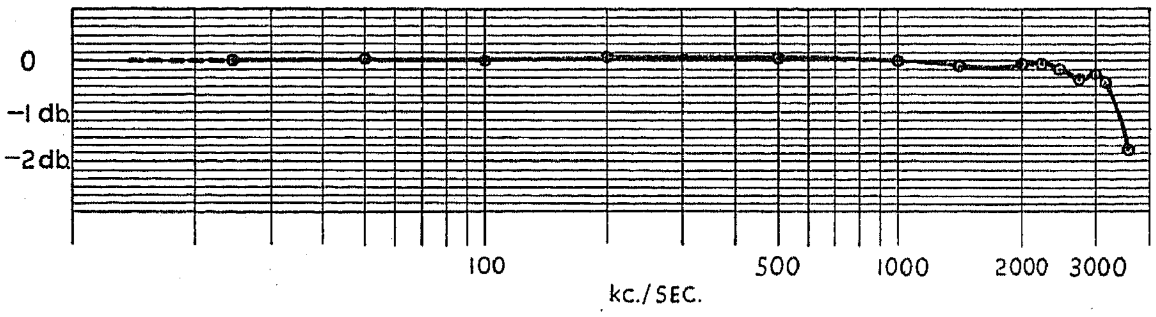

Fig. 15.—Overall frequency characteristic of modulation amplifiers.

(15) ACKNOWLEDGMENTS

The construction of the Alexandra Palace equipment involved the united efforts of a number of engineers. Acknowledgments are due to Mr. I. Shoenberg, Director of Research to Electric and Musical Industries, Ltd., and to Mr. G. E. Condliffe and the staff of the Research Department, among whom Mr. A. D. Blumlein, Mr. E. L. C. White, Mr. E. A. Nind, Mr. J. Hardwick, and Mr. F. Blythen should be mentioned.

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The following is a list of relevant British Patents to which reference may be made for more complete information.

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(2) C. O. Browne, J. Hardwick, F. Blythen, and E. L. C. White: No. 450675.
(3) E. L. C. White: No. 471731.
(4) C. O. Browne and J. Hardwick: No. 419441.
(5) C. O. Browne, E. C. Cork, and M. B. Manifold: No. 448097; A. D. Blumlein, No. 455858.
(6) M. B. Manifold: No. 443952.
(7) M. B. Manifold and A. D. Blumlein: No. 471103.
(8) E. L. C. White: No. 462110.
(9) A. D. Blumlein and E. L. C. White: No. 474607.
(10) E. L. C. White: No. 462536.
(11) E. L. C. White: No. 456450.
(12) C. O. Browne, F. Blythen, and A. D. Blumlein: No. 449242.
(13) A. D. Blumlein: No. 461004.
(14) A. D. Blumlein: No. 448421.
(15) A. D. Blumlein: No. 462530.
(16) A. D. Blumlein: No. 421546.

APPENDIX 1

The Cathode-Follower

General.

The impedance of a triode between cathode and earth, with grid and anode effectively earthed, is

$$\frac{R_a}{m+1} = \frac{m}{m+1} \cdot \frac{R_a}{m} = \frac{m}{m+1} \cdot \frac{1}{g}$$

where m is the amplification factor, R_a is the resistance, and g is the mutual conductance. The open-circuit voltage developed between cathode and earth when E volts are applied to the grid will be

$$\frac{m}{m+1} \cdot E$$

If m is large the open-circuit impedance is therefore approximately equal to the reciprocal of the slope of the valve; and the open-circuit voltage is approximately equal to the input voltage impressed upon the grid. With a cathode resistance large compared with $1/g$, the cathode potential will follow the grid potential both in amplitude and in phase: hence the name "cathode follower" which is given to the circuit. The negative feed-back introduced by the load in the cathode circuit increases the linearity of the valve; the voltage-swing it is capable of handling being limited by the voltage of the H.T. supply.

Cathode-follower circuits are frequently employed in the television equipment, and a number of typical examples of their use are given below.

Case 1. High input impedance: Emitron-camera input circuit.*

The first valve in the head amplifier is a high-slope triode connected as a cathode-follower with large cathode resistance, and it constitutes a low-impedance source for feeding the succeeding amplifier stage. By virtue of the fact that the cathode potential follows the grid potential, the grid-to-cathode capacitance is effectively removed. The capacitance to earth of the signal plate of the Emitron (which is connected to the grid of the first valve) is also reduced by surrounding it with a shield connected to the cathode. The Emitron is worked with a high load-resistance, and compensation is subsequently introduced for the loss of the higher frequencies. A higher input resistance is made possible by the use of a cathode-follower, and the overall result from this arrangement is a better signal/noise ratio than would be realized by a lower input resistance and a conventional amplifier circuit.

Case 2. Low output impedance.

Cables for interconnecting the various units used in the equipment usually take the form of small feeders, and in order that these shall be of a good practicable construction so that they may be handled without fear of breakage the inner conductor consists of a wire of comparatively heavy gauge. In consequence, the characteristic impedance is low, and it is obvious that difficulties will be encountered in feeding lines of this type from the anode circuit of a valve if a direct coupling is used. The practice has therefore been adopted in this equipment of including a cathode-follower in the output circuit of each unit, so that the disadvantage of a high steady potential superimposed upon the output signals is eliminated. This arrangement has the advantage of simplicity, and the circuit is, in general less susceptible to anode-supply impedance and voltage fluctuations.

Case 3. Cathode-follower feeding a capacitive load.

An example of this condition arises in the case of the C.A.T.6 cathode-follower stage of the modulation amplifiers; this stage feeds the television signals into the input capacitance of the radio transmitter and connecting line.

In general, variations of potential at the cathode would lag behind the corresponding variations on the grid by an amount determined by the cathode-circuit time-constant. In the conducting state, the time-constant of the cathode circuit of the valve will be $C \,.\, R/(1 + Rg)$, where C is the capacitance of the load in shunt with the cathode load-resistance R and cathode impedance $1/g$. If, however, a rapid negative pulse of large amplitude is applied to the grid, so that the rate of change of grid potential is appreciably greater than that of cathode potential, the grid may depreciate in potential with respect to the cathode far enough to cut off the anode current. Momentarily, therefore, a longer time-constant, determined by the product of C and R, is operative until the valve again conducts, after which the rapid time-constant will be realized for the completion of the pulse.

In the design of a stage in which this possibility exists, since the rate of discharge of the capacitance is proportional to the voltage across it, it is desirable to make the initial cathode potential as high as possible, by operating the valve with high anode current. In the particular case of the C.A.T.6 cathode-follower, the picture signals are positive, so that it is improbable that the valve would cease to conduct during the reproduction of wave-fronts which are likely to occur in the amplitude range occupied by the picture signals.

Case 4. Cathode-follower as a voltage stabilizer of low regulation impedance.

In order to prevent instability or cross-talk in the equipment, due to interaction between the various units through the H.T. supply circuits, it is necessary to provide a number of effectively independent supply sources of low internal regulation. For this purpose, stabilizing circuits are provided consisting of cathode-follower valves, in the cathode circuits of which the loads it is required to feed are connected. The grids of these valves are held positive with respect to earth by a bias battery.

The open-circuit voltage available at the cathode of the stabilizing valve will be equal to that of the grid-bias battery V_b plus the voltage V_g necessary to reduce the anode current to zero.

Current may be taken by the load from this source, which has, therefore, a regulation impedance approximately equal to $1/g$; a limit (imposed by grid current) to the amount of current available being reached when the open-circuit cathode voltage has been depreciated by V_g to the voltage of the bias battery only.

A variation of supply voltage applied to the anode of the stabilizing valve will be reproduced at the cathode diminished in the ratio $1/(m + 1)$, so that the voltage as applied to the load is effectively stabilized, and is independent of load fluctuations of the H.T. supply due to other parts of the equipment.

APPENDIX 2

Constant-Impedance Networks

It is well known that either of the circuits shown in Figs. 16(a) and 16(b) will present a constant impedance equal to R at all frequencies provided that $L/C = R^2$. Advantage is taken of this property in the design of the television equipment in several instances, some of which are given below.

Case 1. Stray capacitance of a "hold-off" supply.*

Referring to Fig. 17(a), the capacitance of the hold-off supply, here indicated as a battery connected between anode circuit and following grid, may introduce serious loss of the higher frequencies, due to the diminishing impedance of the stray capacitance in shunt with the anode load *R* with increase of frequency. In Fig. 17(*b*) the anode resistance *R* shunted by the stray capacitance of the battery (*C*) is connected in series with an inductance *L* shunted by a second resistance *R*. The value of the inductance is determined by $L = CR^2$, so that the anode load now presents a constant impedance *R* at all frequencies.

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* See Reference (14).

* See Reference (15).

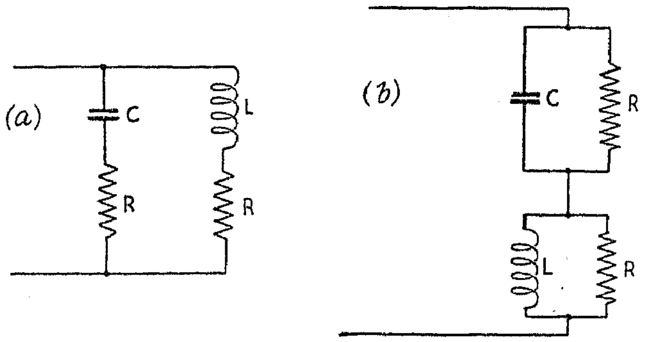

Fig. 16

The negative battery voltage is applied to the grid through a second winding tightly coupled to the first, the mutual inductance between the two windings being made equal to *L*. Assuming negligible grid input impedance, any alternating e.m.f. on the anode will be transmitted to the grid, but the impedance facing the grid will be increased by the leakage inductance *l* of the two coils. By comparison with the circuit of Fig. 16(*a*), if *r* is the resistance of the battery the impedance of *l* and *r* in series can be made constant by connecting a condenser and resistance in series between anode and grid of the two valves, where the condenser capacitance is given by $C_1 = l/r^2$.

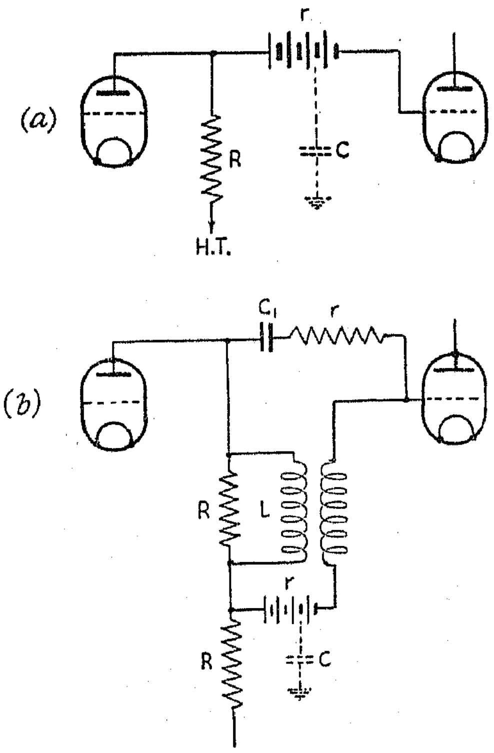

Fig. 17

The circuit of Fig. 17(*b*) will now be equivalent to that of Fig. 17(*a*), except that the effect of the stray capacitance of the battery has been completely removed.

Case 2. Filament-heating generator for cathode-follower.

A circuit shown in Fig. 18 is used by which the capacitance of a filament generator may effectively be removed from the cathode of a cathode-follower valve. In this case the inductance consists of a bifilar winding through which the filament-heating current is passed. The coil is shunted by a resistance equal to the cathode load-resistance *R*, and has inductance determined by $L = CR^2$, where *C* is the capacitance of the generator to earth.

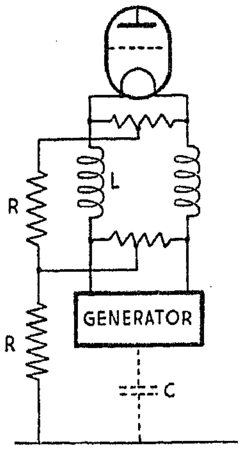

Fig. 18

Case 3. Hold-off supply and filament-heating generator.

In the case in which it is required to include a hold-off voltage supply S_1 in addition to a filament generator S_2, the capacitance to earth of the hold-off supply (C_1) is included in a circuit of constant impedance equal to *R*, as shown in Fig. 19, where the inductance of the coils is $L_1 = C_1R^2$, and *R* is given as the cathode load resistance. The effective impedance *R* of this circuit is shunted to earth by the capacitance C_2 of the filament generator S_2, and the combination is made part of a further constant-impedance circuit by the generator inductance L_2 shunted by *R*. The value of L_2 is given by $L_2 = C_2R_2$.

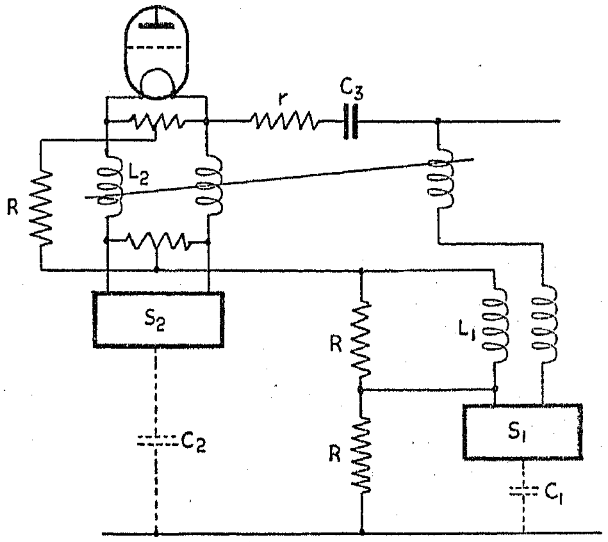

Fig. 19

In order to pass the negative voltage of the hold-off source to the following grid, a third winding is provided which is tightly coupled to L_2. As in Case 1, the leakage inductances l_1 and l_2, which are effectively in series with the resistance r of the hold-off supply S_1, are corrected by the resistance r and the condenser C_3 in series, where $C_3 = (l_1 + l_2)/r^2$.

In the particular case of the filament generator and hold-off for the main modulation-amplifier stage, the capacitance between the tightly-coupled windings was, such as to resonate within the working frequency-range with the leakage inductance. This capacitance, together with the leakage inductance, made an effective transmission line and was treated as such.

Case 4. H.T. smoothing circuits.*

The circuit shown in Fig. 20 is typical of that used for H.T. smoothing in the equipment. Each section of the circuit is made to appear as a constant impedance equal to R, where R is the regulation resistance of the rectifier, by choosing values for the chokes and condensers such that $L = CR^2$. The values of R and L may, of course, be chosen to account for regulation due to the reactance of the supply mains, transformer, etc. The final stage of smoothing has been shown inverted with respect to the preceding stages; an alternative arrangement which still preserves the constant-impedance properties of the network.

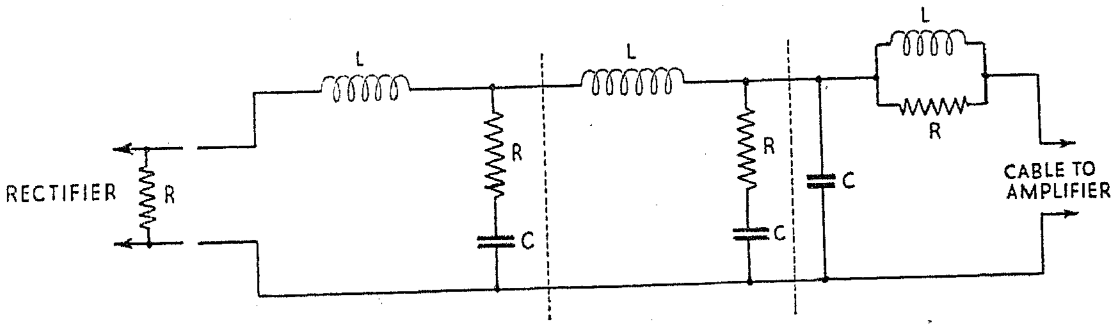

Fig. 20

The cables connecting the H.T. supply circuits to the corresponding amplifiers present considerable capacitance between the positive conductor and earth. This capacitance is shunted at the supply-unit end by the constant impedance of the smoothing circuit, and the cable is made to present a constant impedance to the amplifier by connecting, in series with it, the appropriate inductance and resistance in parallel.

PART III

THE RADIO TRANSMITTER

By N. E. DAVIS and E. GREEN, M.Sc.

(*First received* 3*rd December*, 1937, *and in final form* 10*th March*, 1938.)

SUMMARY

This Part of the paper sets out the agreed specification of the vision transmitter of the London Television Station. Details of the valves available for meeting the requirements are given, and their calculated performance in the balanced bridge circuit of the final modulated amplifier is outlined. This is followed by an examination of:—

(1) The mechanical assembly, with particular reference to the essential features governing the design of the various components.

(2) The control of the amplifier by the television signal, and the conditions relating grid input-volts and output-power to the aerial feeder.

(3) Special requirements of the system.

The Appendix includes a note on the determination of the compensating capacitance for grid-lead reactance, and general data regarding the transmitter.

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(1) INTRODUCTION

The Marconi-E.M.I. radio transmitter at Alexandra Palace is the product of continuous research and development initiated early in 1931. At that date the E.M.I. scanning equipment employed a mirror drum producing 120-line pictures, 25 pictures per sec., with sequential scanning, and required a signalling frequency-band of 0 to 180 kc./sec.

The first experimental transmitter, of peak power 400 W on 44 Mc./sec., was installed at Hayes and used for the development of a basic system of modulation for the efficient and accurate transmission of television signals according to the wave-form specification described in Part I of this paper. During 1932, the first high-frequency Class B power amplifier, to operate on the ultra-short-wave band, was built. The peak power was increased to 4 kW, and at the same time the picture frequency-band width was increased to about 400 kc./sec., corresponding to a 180-line picture, 25 pictures per sec.

1933–34 saw the peak power raised to 12 kW and the band width increased to about 1 Mc./sec., the picture definition having been increased to 240 lines, 25 pictures per sec.

In the spring of 1935, the number of lines per picture was increased to 405, and interlaced scanning was adopted. This involved a further increase in the picture frequency-band, which now extended from zero to 2·5 Mc./sec. At this time, designs for a further increase in power of the transmitter were considered.

Eighteen months later, i.e. during August, 1936, the Alexandra Palace transmitter was installed and in operation.

(2) TRANSMITTER SPECIFICATION

This was as follows:—

Output power.

The transmitter shall be capable of giving an output power to the terminals of the high-frequency (h.f.)

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* See Reference (16).

feeder of 17 kW when a steady condition is maintained corresponding to the transmission of a full white picture.

Wavelength.

The working frequency shall be 45 Mc./sec., corresponding to a wavelength of 6·67 m.

Modulation.

The frequency and amplitude response of the transmitter shall be such that the conditions required by the contractor's system of high-definition television—employing 405 lines, 25 pictures per sec., interlaced, to give 50 frames per sec., each of 202·5 lines—shall be satisfied.

Summarized, the conditions to be met are: 17 kW peak output at 45 Mc./sec., effectively modulated over a total band width of 5 Mc./sec.

(3) TRANSMITTING VALVES

The specification of the transmitter was based on experimental knowledge and calculated performance of a final grid-modulated power amplifier employing two C.A.T.9 Marconi valves operating in a balanced bridge circuit.

A valve of this type is shown in Fig. 21 (Plate 2), and approximate data for it are as follows:—

Filament volts:	18–20 volts,
Filament current:	100 amperes,
Anode volts:	9 000/15 000 volts,
Emission current at 90 % saturation:	12 amperes,
Maximum anode loss:	18 kW,
Amplification factor:	45,
Impedance:	4 500 ohms,
Length of anode:	12 in.,

Inter-electrode capacitance: grid to anode, 17·6 $\mu\mu$F; anode to filament (earth), 16·0 $\mu\mu$F; grid to filament, 29·2 $\mu\mu$F.

The expected performance of a pair of these valves operating at 45 Mc./sec. in a push-pull circuit capable of effective modulation over a total band-width of 5·0 Mc. may now be examined. The constants of the anode circuit will be chiefly determined by the valve capacitances. Assuming that in the bridge circuit the grid-to-anode balancing condensers are equivalent in capacitance to the valve, the contribution from this source plus the anode-earth (filament) will be 25·6 $\mu\mu$F. To this must be added the capacitance to space of the valve jackets and the members necessary to provide surfaces for balancing and tuning purposes, as well as the minimum capacitance of the variable tuning member. When these are taken into account a minimum figure for the total anode-circuit capacitance will be about 32 $\mu\mu$F. At a frequency of 45 Mc./sec. the capacitive reactance of the anode circuit will be 110 Ω, and the inductance, of equal reactance value, 0·39 μH.

With these values in mind we may now determine the impedance into which the valve must work and the operating conditions which follow from it. As a basis of design it was decided that the Q value of the anode circuit should be such as to give half power response when the circuit was excited by frequencies 2·5 Mc./sec. above or below the carrier frequency.

Let

f = carrier frequency = 45 × 10^6 cycles per sec.,
$\omega = 2\pi f$,
Δf = frequency-difference between two half-power points = 5 × 10^6 cycles per sec.,
C = capacitance of anode circuit = 32 $\mu\mu$F,
L = inductance of anode circuit = 0·39 μH,
I = available emission per valve = 12 A,
R = effective series resistance of anode circuit,
R' = effective load on each valve during the active half-cycle,
I_0 = oscillating current in anode circuit,
V = d.c. anode voltage,
v = minimum anode volts,
and $2(V - v)$ = peak h.f. volts across anode circuit.

Then we have

$$\frac{\Delta f}{f} = \frac{1}{Q} = \frac{R}{L\omega} = RC\omega \quad . \quad . \quad . \quad . \quad (1)$$

$$R = \frac{\Delta f}{f} \times \frac{1}{C\omega} = \frac{5}{45} \times 110 = 12\cdot 2 \text{ ohms}$$

As each valve works into half the circuit for half the time,

$$R' = \left(\frac{L\omega}{2}\right)^2\left(\frac{1}{R}\right) = \left(\frac{1}{2C\omega}\right)^2\left(\frac{fC\omega}{\Delta f}\right) = \frac{f}{4C\omega\Delta f}$$

$$R' = \frac{1}{8\pi C\Delta f} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$R' = 250 \text{ ohms}$$

If the full emission, I, is to be used,

$$V - v = R'I = 250 \times 12 = 3\,000 \text{ volts}$$

$$V - v = \frac{I}{8\pi C\Delta f} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\text{Maximum output} = \frac{(V - v)I}{2} = \frac{I^2}{16\pi C\Delta f} \quad . \quad (4)$$

Fig. 22 shows the anode-current/anode-voltage characteristics of the C.A.T.9 valves, with the load line AB set in a suitable position. The maximum useful anode voltage is limited to 5 500 volts, no matter what the nominal working voltage of the valve may be. The half-ellipse shown is the load line for the extreme side-band frequencies, and lies reasonably within the linear portion of the characteristics.

$$\text{Peak power input} = \frac{2VI}{\pi} = \frac{2 \times 5\,500 \times 12}{\pi}$$
$$= 42 \text{ kW}$$

$$\text{Peak power output} = \frac{(V - v)I}{2} = \frac{3\,000 \times 12}{2}$$
$$= 18 \text{ kW}$$

$$\text{Peak efficiency} = \frac{18}{42} = 43\ \%$$

$$\text{D.C. grid bias} = -\ 150 \text{ volts}$$

$$\text{Peak grid-swing} = 1\,500 \text{ volts}$$

These theoretical figures for loading conditions, power output, and frequency response, agree very closely with those actually obtained.

Equations (3) and (4) are useful for judging the possibilities of a valve for television purposes. They show that the maximum allowable anode-swing and the output are determined by the peak emission, the circuit capacitance (which is determined by the valve capacitances), and the band width.

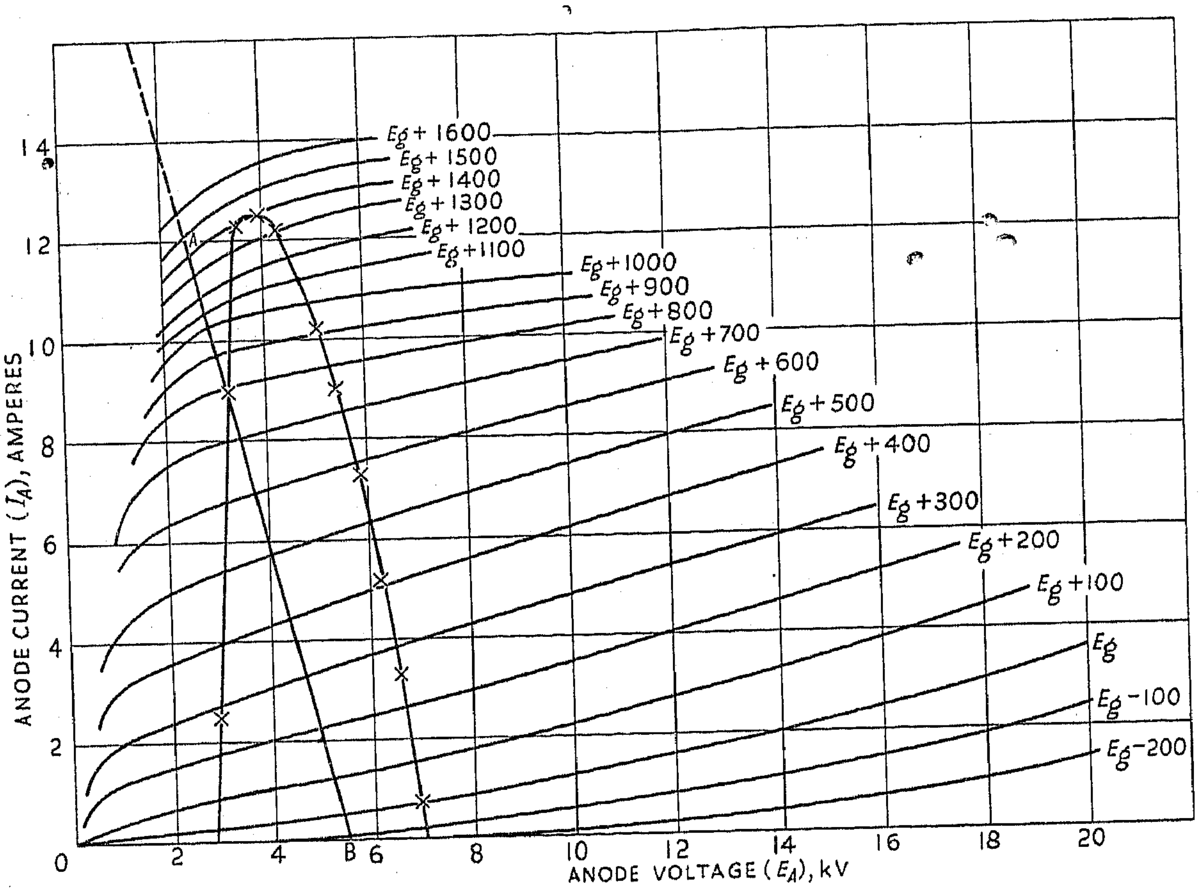

Fig. 22.—C.A.T.9 anode-voltage/anode-current characteristics.

For a valve to be suitable for wide-band television the ratio of peak emission to grid-anode capacitance should be as high as possible. Beyond a certain point, however, this capacitance can only be reduced at the expense of transit time. The C.A.T.9 valves are a good compromise in this respect, as although the effects of transit time are apparent in loading of the grid circuit the transit time does not seriously affect the efficiency.

If, however, the required sideband-width were doubled the maximum possible anode-swing and output would be halved, and the efficiency much lower. The carrier frequency is not involved in equations (3) and (4), but only the sideband width. Hence increase of carrier frequency will not give the valves any easier conditions by reducing $\Delta f/f$.

A further point of importance is that the inductance of the connections inside the valve, both for the grid and for the filament, but especially for the grid, should be kept as small as possible. The reason for this will be disclosed when the fundamental circuits are being discussed.

(4) FUNDAMENTAL CIRCUIT

The schematic arrangement of the bridge circuit of the final amplifier is shown in Fig. 23, and the two preceding stages are similar. The arrangement does not differ from that used in the normal commercial short-wave band, except in the care given to mechanical details to maintain symmetry and keep the circuit capacitances and the inductance of high-frequency connections down to the absolute minimum.

The ideal condition to be fulfilled is that the bridge should remain balanced over the whole range of carrier and sidebands, i.e. any voltage across B_1B_2 shall produce no voltage at D_1 and D_2 or at the active grids G_1G_2. The condition as regards D_1D_2 is fulfilled if the resultant inductances and capacitances in the arms are equal, each

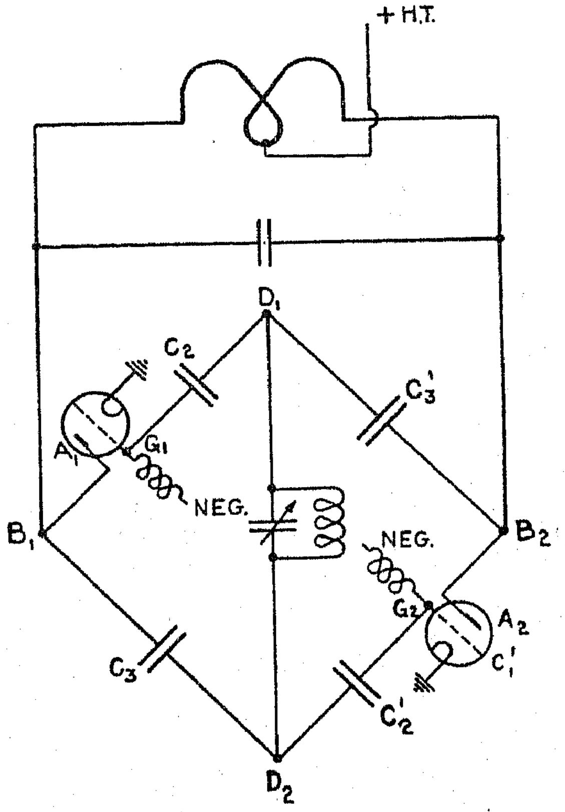

Fig. 23.—The fundamental circuit.

to each. This can be ensured by careful mechanical design.

For no volts at G_1 and G_2 we must have zero reactance between G_1 and D_1 and G_2 and D_2, since a large proportion of the h.f. current in the plate circuit flows across the bridge. This condition is fulfilled at the carrier frequency by inserting the condensers C_2, C_2'. For the sidebands there will be a small residual voltage at G_1 and G_2 which will tend to depress one sideband and augment the other.

For the C.A.T.9 valves the quantitative relations are set out below.

Let C_1 = grid-anode capacitance = $17\cdot5\ \mu\mu\text{F}$,
l = inductance of grid lead = $0\cdot125\ \mu\text{H}$,
$\omega = 2\pi \times \text{frequency} = 2\pi \times 45 \times 10^6$,
$\delta\omega = 2\pi \times \text{change of frequency} = 2\pi \times 2\cdot5 \times 10^6$ for extreme sidebands,

$$C_2 = \left.\begin{array}{l}\text{capacitance such that}\\ \quad l\omega - \dfrac{1}{C_2\omega} = 0\end{array}\right\} = 100\ \mu\mu\text{F},$$

V = maximum anode voltage-swing = 3 000 volts,
and v_g = voltage developed at G_1 or G_2 due to V.

Then at the carrier frequency, if the condensers C_2 and C_2' were not present,

$$v_g = VC_1\omega l\omega = VC_1 l\omega^2$$

$$= \frac{C_1}{C_2}V = 530 \text{ volts}$$

This compares with a driving voltage on the grid side of about 1 500 volts. The voltage is in the correct phase to maintain oscillations. After the insertion of C_2, we have

$$v_g = VC_1\omega\left[l\omega - \frac{1}{C_2\omega}\right]$$

$$\frac{dv_g}{d\omega} = 2VC_1\omega l$$

For the extreme sidebands,

$$\delta v_g = 2VC_1\omega l\delta\omega$$

$$= \frac{C_1}{C_2}V\left(2\frac{\delta\omega}{\omega}\right)$$

$$= \frac{530 \times 2 \times 2\cdot5}{45} = 56 \text{ volts}$$

This residual voltage is proportional to l, and hence the importance of reducing this to a minimum.

Provided, therefore, that the loading of the anode circuit is established as indicated above, the frequency response of the transmitter should be effective over the desired band-width and the amplifier capable of delivering a peak power of 18 kW. For this requirement to be fulfilled, however, a very important condition arises, namely that the impedance of the aerial system constituting the load should be constant and resistive over the complete modulation band-width.

The aerial and feeder problem is dealt with in a separate paper.

(5) 45-Mc. MODULATED AMPLIFIER: CONSTRUCTIONAL DETAILS, AND FEATURES GOVERNING DESIGN OF COMPONENTS

General

The mechanical-electrical assembly of the ultra-short-wave bridge circuit embodying water-cooled triodes must be considered in relation to the type and constructional arrangement of the valves. The relative disposition of the electrodes will determine whether or not a favourable balance of mechanical arrangement and electrical characteristics may be attained.

From this point of view the "single-ended" valve, in which the grid connection is brought out through the same glass envelope as the filament, has some advantage over the double-ended type, in which the grid connection emerges through a separate glass envelope. With this latter type of valve the electrical circuit tends to spread in dimension a comparable fraction of the operating wavelength and, in addition, it is difficult to arrange an assembly in which the grid-to-anode balancing capacitances are of sufficiently low inductance. Furthermore, the geometric disposition of the grid-filament electrodes and connections within the valves results naturally in a circuit of higher inductance than that normal to the disposition of the same elements and connections in the single-ended type.

As previously indicated, the inter-electrode capacitances of the valves represent the principal electrical constant of the circuit. On the other hand, every additional metal member added possesses distributed capacitance and inductance, and it is desirable that a favourable ratio of the total anode inductance should be available for coupling to the load. The main assembly, providing the balancing capacitance and tuning areas, is therefore preferably arranged in relation to the points of attachment of the main inductance and valve anodes so as to result in an interconnection of negligible impedance.

In the disposition of the grid-to-anode balancing members the preferred location will transfer the inevitable inter-capacitances from the anode to the grid side of the circuit, and at the same time facilitate a symmetrical rigid construction of low inductance in these arms of the bridge.

Finally, in order to avoid losses and unwanted additional anode capacitance, the insulated inlet and outlet positions of the water-cooling system should be embodied in the assembly at a point of zero, or almost zero, h.f. potential.

The ideal assembly from the mechanical and electrical point of view would probably be a self-contained block design arranged to receive the valves, and incorporating enclosed waterways and balancing and main condenser surfaces.

The ultra-short-wave amplifier to be described represents a slight compromise in design, in that the standard valve anode water-cooling jackets have been retained, although practically all the desirable features as outlined above have been realized.

Fig. 24 and Fig. 25 are respectively front and side elevation drawings of the final modulated power amplifier of the London Television Transmitter.

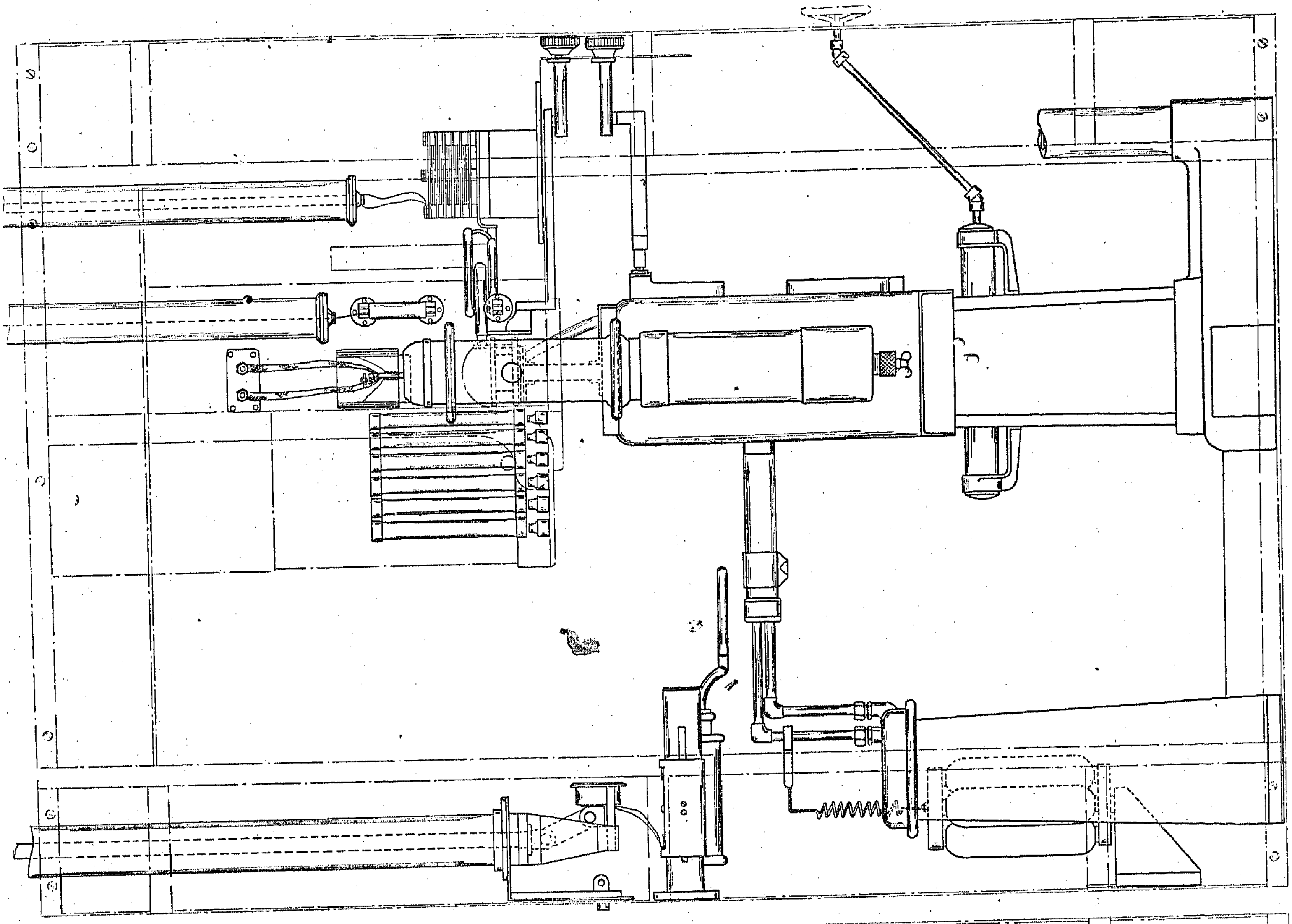

Fig. 25.—Side elevation of modulated power amplifier.

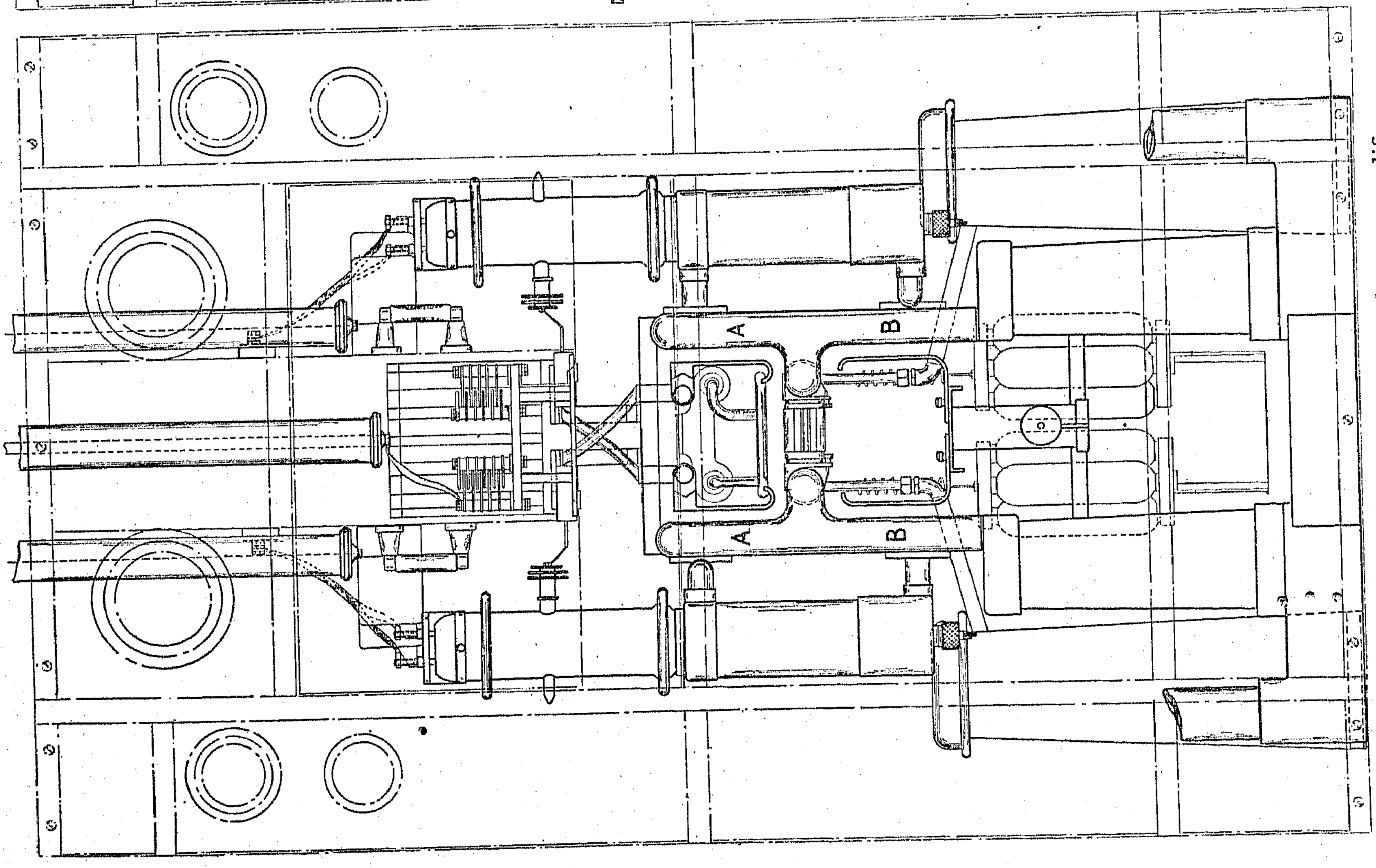

Fig. 24.—Front elevation of modulated power amplifier.

Anode Assembly

Each valve is symmetrically mounted on the vertical outside face of a specially shaped hollow copper member, the other face of which is provided with a short horizontal portion serving to create two independent anode areas A and B. These at the same time provide points of attachment for the external anode inductance, and entrance for the inlet and outlet water connections.

Each member is separately insulated and rigidly fixed to the common base casting by means of mycalex slabs, and the structure is further strengthened by a mycalex cross-tie, which also carries the grid-circuit components.

The anode area A provides the fixed plate of the anode-to-grid balancing capacitance for each valve, while the areas B serve as the fixed portions of the anode-circuit tuning condenser.

The inlet and outlet waterways are formed inside the hollow anode member and terminate in faced surfaces, corresponding with the flanges of the valve jacket, which provide the necessary support, watertight joints, and electrical connection.

Anode Tuning Capacitance

The variable portion of the anode-circuit tuning condenser is a U-shaped structure of depth equal to the anode members, capable of complete withdrawal by means of a travelling nut mechanism cylindrically housed, and controlled from the front panel. The maximum fixed value of the condenser may be altered by lateral adjustment of the plates, and is a valuable feature of the design. It combines the flexibility of adjustment of a comparatively large capacitance with the facility of finally arranging the minimum value convenient for the attainment of maximum impedance of the anode circuit at the operating frequency.

Balancing Capacitances

The variable plates of the grid-to-anode balancing condensers are mounted on integrally-arranged circular guides, the fixed portion of which passes through to the top of the mycalex cross-tie so as to provide ample electrical contact surfaces in the correct position for a natural cross-connection to the grid points of the bridge. The movement of each plate is limited to a partial withdrawal from the anode surface, and is governed by a small travelling nut control, fixed towards the front of the panel, and accessible through metal flaps, which are permanently shut by the front screen during operation of the amplifier.

The inside location of the plates results in a disposition favourable to the attainment of low inductive reactance in the balancing-condenser arms, and also ensures a particularly rigid and symmetrical structure for the attachment of the grid-reactance condensers and grid-circuit tuning inductance.

Grid-Reactance Condensers

Under the conditions of operation of the amplifier, which have already been described, the high-frequency current entering the grid seals will reach a maximum r.m.s. value of 25 to 30 amperes, and the capacitance necessary to neutralize the inductive reactance of the grid-filament structure of the C.A.T.9 type of valve at a frequency of 45 Mc./sec. is of the order of 100 $\mu\mu$F. This defines the limits of design of these condensers, and the full requirement is met by providing an open mica-dielectric assembly, built symmetrically about a substantial single copper plate, so located with respect to the valve grid that a very short interconnection serves to complete the circuit.

The use of these condensers allows the filaments of the valves to be directly earthed without affecting efficiency of operation. Care is taken, however, to limit the inductance of the filament to that contained within the valve structure by providing substantial h.f. bypass condensers to earth at the seals and the point of connection of the d.c. lighting leads.

Grid-Circuit Inductance

The total capacitance presented at the grid points of the bridge is approximately 60 $\mu\mu$F, and the grid-circuit inductance required for a frequency of 45 Mc./sec. is therefore of the order of 0·2 μH. This is obtained by an adjustable trombone, the fixed legs of which are of $\frac{1}{2}$-in. diameter copper tube spaced 2 in. apart. This principle of construction results in a good ratio of loop dimension to inductance, and facilitates magnetic coupling to the exciting amplifier. The loop is cooled by an air stream through the tubes, the point of entry being at the electrical centre so that no electrical unbalance may arise from the necessary attachments. It is of interest to observe that this is a case in which air cooling is justified, as if this is dispensed with by increasing the diameter of the tubes the corresponding decrease in inductance tends to a large and clumsy construction.

The grid coil is coupled magnetically to the output of the exciting amplifier by means of a series-tuned circuit which forms the termination of a 75-ohm concentric feeder. This form of coupling has the advantage of introducing very little extra capacitance.

The series circuit consists of a 2-turn coil, mechanically and electrically centralized with reference to two small variable capacitances of the flat-plate type. The free side of one condenser is connected, by a flexible lead, to the inner, and the other to the outer and earthed conductor of the feeder. The arrangement assists in maintaining the electrical balance of the grid circuit with the use of the unbalanced screened feeder.

The assembly is built up as a self-contained unit, and may be removed completely from the panel, tuned as an independent circuit, and the condensers locked. The condition of symmetry, maintenance of tune, and variability of coupling, is realized by arranging the complete unit to be movable in guides, relative to the fixed coil of the grid circuit.

Grid Damping Resistance

The amplifier is modulated by arranging the television signals to control the negative bias of the grids while these are constantly excited at the operating frequency of 45 Mc./sec. The exact relation between the negative voltage applied by the television signals and the h.f. amplifier output is presented in another section of the paper. It may, however, be noted here that, at vision white, the grids are at the correct voltage for the h.f. amplifier to operate in a truly Class B condition, and that the tips of the synchronizing pulses correspond to a negative grid voltage somewhat greater than that of the h.f. excitation, and, therefore, zero output.

Under these conditions, maximum linearity of control is realized if the h.f. impedance looking into the grids is constant between the two limits of modulation. In an ultra-short-wave Class B amplifier of the type under discussion this presents a very special difficulty owing to the large proportion of the power, available for grid excitation, which is transferred to the valve anodes and anode circuit. This effect is due mainly to the time of transit of the electrons from the cathode to the anode, within the valve structure, being an appreciable fraction of the h.f. cycle, and which, for the C.A.T.9 valves operating as set out above, appears to be equivalent to about 20 degrees.

With a grid peak excitation of 1 600 volts an anode loss of 2 kW has been measured at zero anode voltage, and during normal operation the loss is probably about 1·5 kW.

In the medium-wave broadcast band it is practicable to keep the impedance of the grid circuits of the h.f. Class B amplifiers appreciably constant during the modulation cycle, and usually only about one-tenth of the available power output of the driving or exciting amplifier is expended in the actual grid circuit; the remaining nine-tenths being absorbed by the damping resistance. It will be realized that to obtain a similar condition in the ultra-short-wave television amplifier would necessitate a driving power considerably in excess of that delivered to the aerial.

At the London Station the maximum power available for excitation of the grids of the modulated amplifier is 6 kW, and this is expended as follows: grid damping resistances, 3 kW; valve anodes, 1·5 kW; grid circuit, 1·5 kW.

The static modulation characteristic of the amplifier, given later, discloses considerable bottom bending, and there is no doubt this could be greatly improved if more power were available. On the other hand, the general linearity is good, and the synchronizing pulses are the only signals affected by the curvature. These are not distorted in shape, but only modified in amplitude, and this may be corrected by increasing the modulation input voltage of this portion of the signal. This is a distinct advantage of the Marconi-E.M.I. form of transmission.

The manner in which the load impedance of the exciting stage is to be stabilized is of some interest. In the 12-kW transmitter at Hayes, mentioned in the Introduction, resistance damping was distributed throughout the circuits. The anode inductance, which is water-cooled, is formed of copper tube sprayed externally with soft iron; the grid-circuit inductance of the modulated amplifier is entirely of soft iron, and air-cooled. This arrangement has the advantage of avoiding additional bulk capacitances around the grids, which is important from the point of view of modulation and general high-frequency symmetry. This system was also adopted for the mobile transmitter, operating at 64 Mc./sec., which has been built for outside broadcasts. By specially shaping the iron in the circuits, and proportioning the power more favourably, the load impedance of the exciting amplifier is made appreciably constant without introducing any additional resistances.

For the London high-power transmitter it was decided to place the whole of the damping in the grid circuit of the modulated amplifier, so as to obtain the best possible linearity of control under the conditions presented. The resistance consists of 16 carbon tubes, connected in series, mounted in rigid symmetry on the grid points of the bridge in a circular air shaft which forms part of the grid-circuit compartment. Each tube is supported on a steatite nozzle connected to a common air-duct—also an integral part of the construction. Air is thus passed through each rod, and a suction fan, mounted at the head of the shaft, quickly removes the hot air from the compartment, and generally assists cooling.

In order to minimize h.f. capacitance effects and equalize the loading, the tubes are graded from a value of 25 ohms at the grid ends to 70 ohms towards the electrical centre and point of zero high-frequency potential. The measured d.c. resistance of the bank is 800 ohms, and at 45 Mc./sec. it is equivalent to a grid shunt resistance of 1 600 ohms.

Anode Circuit

The external anode-circuit inductance is obtained by enveloping the inlet and outlet water-piping by a 2-in. copper tube, which is built as a natural extension to the horizontal portion of the anode members. These two parallel tubes are 11 in. long and spaced 4 in. apart.

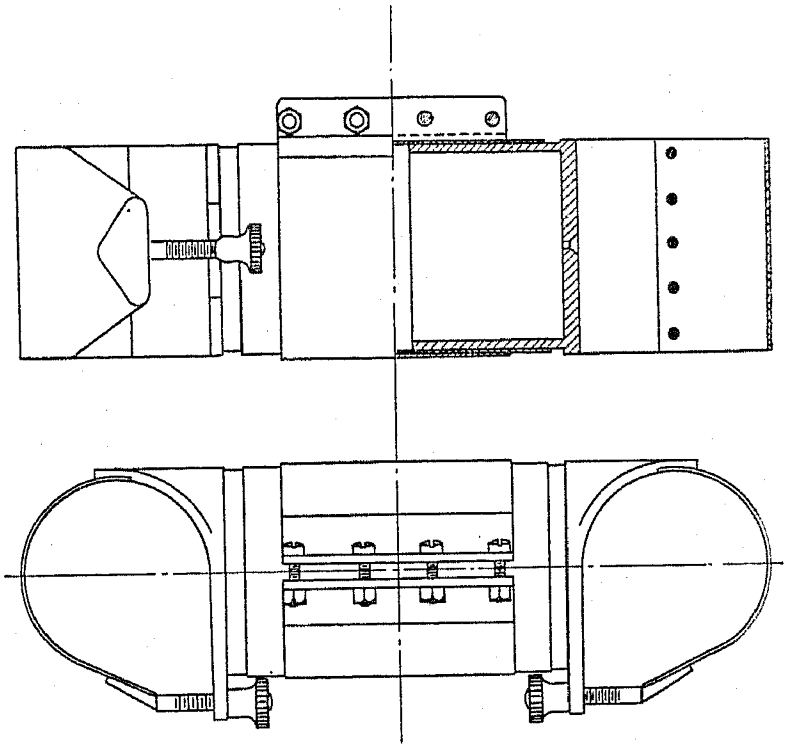

Fig. 26.—Anode-circuit blocking condenser.

The H.T. supply to each valve is connected to the inductance via the water piping, and, as it is desirable that the performance of each valve may be observed, separate anode d.c. feed metering is arranged for by completing the h.f. circuit through a specially designed d.c. blocking condenser mounted between, and capable of adjustment relative to, the inductance tubes.

During the heavily loaded condition of normal operation, the maximum h.f. current in the circuit is about 40 amperes, but this will rise to 90 amperes at no-load. The blocking condenser is therefore designed to carry 100 amperes at 45 Mc./sec. continuously, without undue heating. The construction adopted is shown in Fig. 26.

It is best understood by imagining that the two parallel inductance tubes are formed into an adjustable loop by a $2\frac{1}{4}$-in. diameter copper tube retained in position by phosphor-bronze bands. This interconnecting tube is cut in half, leaving an air-gap of about $\frac{3}{16}$ in., and a sheet of mica placed centrally to the slot envelopes the tube throughout its length. A phosphor-bronze band of slightly less width than the mica sheet is placed symmetrically with respect to it and finally tightened, so that the whole becomes a series tubular mica condenser with the two half-tubes forming the inner plates and the external metal band the common outer plate. Its capacitance as designed is 0·002 μF.

The tubular construction secures an even distribution of the h.f. currents: in addition, the mechanical accuracy with which the main members may be turned, together with the facility afforded for high-pressure location of the metal band over the mica dielectric, removes all possibility of air pockets and ensures a condenser of true characteristics at the ultra-high frequency. This is important, as the inlet and outlet of the cooling water are at this point, and it is desirable that definite control of the h.f. potential should be secured so that water loss in the insulating columns is avoided.

An ordinary multiple flat-plate mica condenser is quite inadequate to fulfil the requirements, besides being less neat and considerably more costly than the condenser designed by the authors. This component is a further illustration of the fact that the ultra-short-wave band requires its own special technique.

Output Coupling Unit

This is a series-tuned circuit designed to operate into 50 ohms. It is so constructed as to be self-contained, both mechanically and electrically, and may be independently tuned either in position or when removed from the panel. The design aims at a high ratio of active to inactive inductance, and also, by minimizing stray capacitances to earth, at complete transfer of the anode-circuit energy to the output feeder. Referring to Fig. 27, it will be seen that the inductance is a flat coil, the free ends of which are developed as the inner members of two separate tubular condensers. The outer tubes are spaced by a mycalex plate, to which they are fixed. Locking guides, mounted on this plate, also carry a mycalex assembly centralizing the inners of each condenser and providing tuning adjustment. The arrangement is completed by a tubular support, which houses a travelling attachment to which one outer tube is fastened; this facilitates external adjustment of the complete unit with reference to the anode-circuit inductance and at the same time constitutes a substantial earth path of low inductance. The outer tube of the second condenser is connected by a flexible strip and h.f. ammeter to a link switch so that the transmitter output may be taken either to the aerial or to test feeders.

Modulation Input

The modulation input, inside the panel, is connected to each grid via an h.f. choke and a separate screened conductor. These conductors are terminated in a junction box (not shown in Fig. 27) mounted externally to the panel, in which a common connection is made to the modulator output, and a monitoring point established.

(6) THE TELEVISION SIGNAL

The wave-form of the television signal as applied to the radio transmitter is illustrated in Fig. 28. The output power of the final h.f. amplifier is plotted from actual test figures as a function of grid negative volts. The vision wave-form, in terms of the negative grid-voltage scale, is projected on to the curves, and the black-level condition is clearly shown. The vision signals are to the right of the black datum and, for high lights, extend to full output. Intermediate light values attain proportionate outputs from the fixed black level. The synchronizing pulses lie to the left of the black level and are of such amplitude, in terms of grid negative voltage, as completely to shut off the transmitter. It will thus be seen that the h.f. amplifier is fully exploited by the complete voltage-swing of the vision and synchronizing signals, and that the former occupy fully the linear portion of the characteristic.

The peak voltage ratio of these signals, as applied to the grids of the valves, is proportioned so as to result in

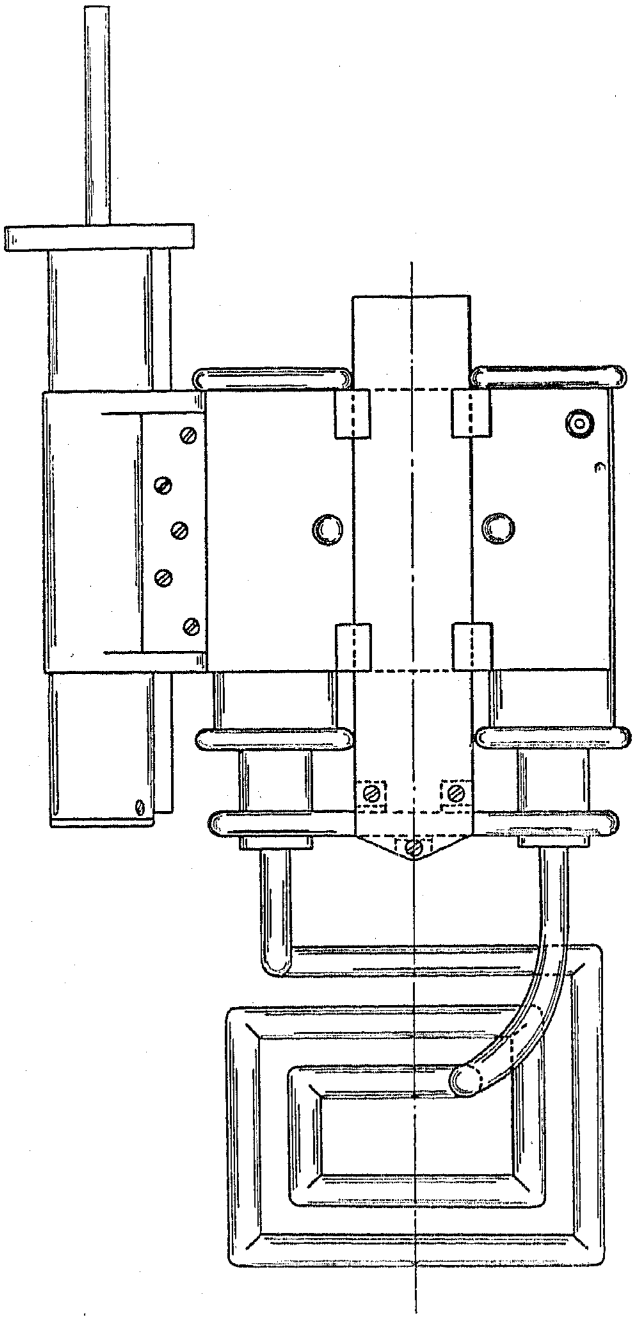

Fig. 27.—Output coupling unit.

an aerial-current output ratio of 10 : 3 between peak white and black level. This corresponds to a radiated signal which, measured from the black datum, defines the limit allotted to the vision and synchronizing signals as having an amplitude ratio of 7 : 3 and constitutes the specified wave-form of the Marconi-E.M.I. system of television.

The input grid peak-voltage ratio shown is 4·5 : 3, but as the amplitude of the synchronizing pulses is increased beyond zero output so as to ensure the desired rectangular wave-form, the operating ratio is usually very nearly unity.

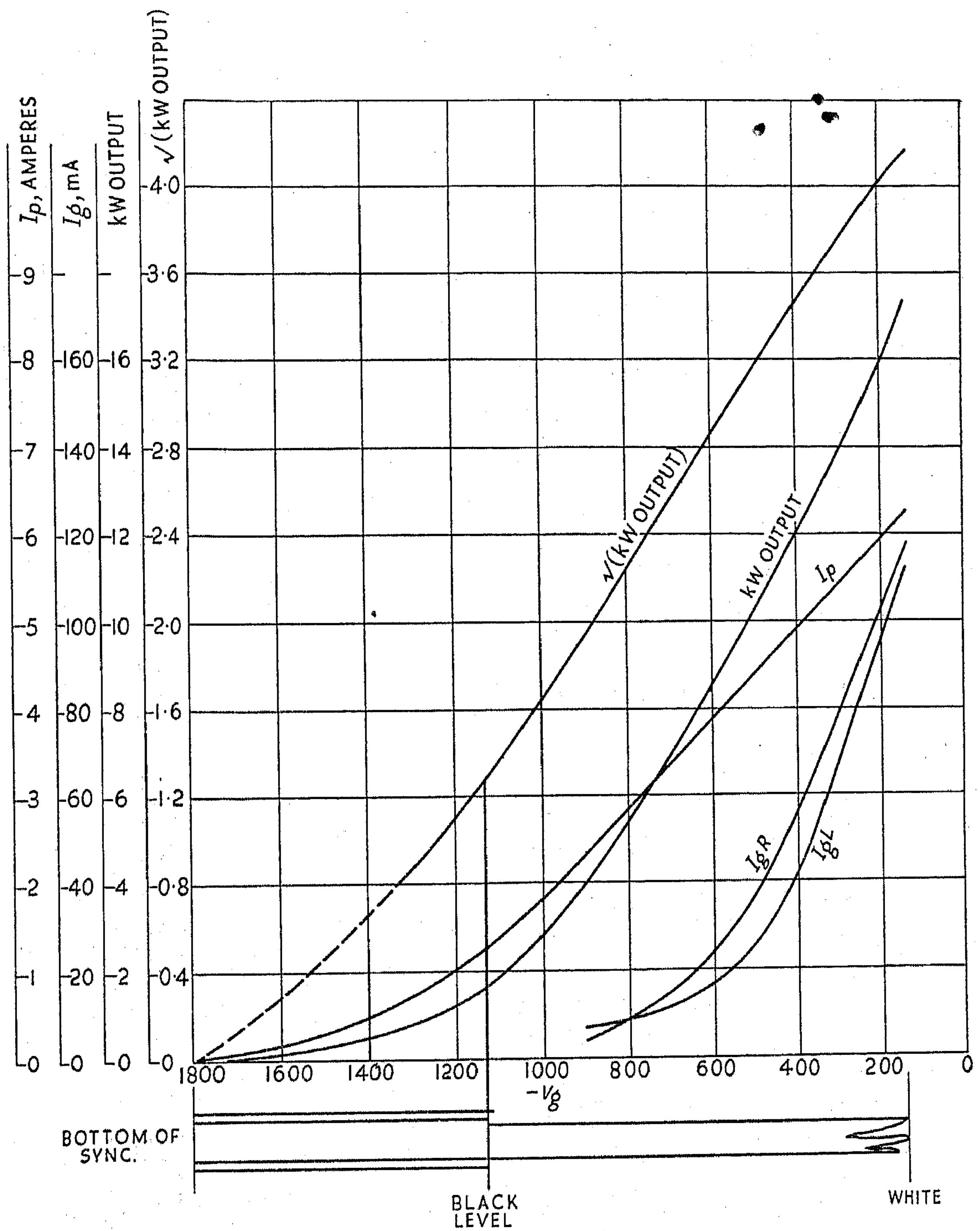

Fig. 28.—C.A.T.9 modulated amplifier. Static characteristic connecting grid negative voltage with output power under constant h.f. excitation.

From the above it will be realized that the Marconi-E.M.I. method of modulation described is akin to that employed in the radio transmission of black-and-white facsimiles. In this case the modulated h.f. amplifier is keyed between two levels of output, one of which represents black and the other white. In the television transmission of a black-and-white film cartoon a similar condition obtains, the h.f. amplifier being keyed between a prearranged low level, to represent the black elements of the film, and full output, to represent the white background. The only difference is that, whereas in facsimile transmission independent synchronization allows one of the levels to be zero output, in television transmission the height of the level corresponding to black must be such as to reserve sufficient power to convey effectively the necessary synchronizing intelligence to the limit of the range of the vision signals. In the television transmission of half tones the h.f. power amplifier is subjected to proportionate keying between the extremes of the black and white levels as defined above.

This form of transmission is known as " d.c. modulation "—in contradistinction to " a.c. modulation," in which the vision signals float about a mean carrier according to the balance of the black to white areas of the elements being transmitted. For a useful detected voltage at the receiver this system results in a great saving of power at the transmitter when compared with a.c. modulation. The foregoing will clarify the meaning of the term as applied to the radio transmitter.

(7) ANODE-VOLTAGE SUPPLY TO THE MODULATED AMPLIFIER

When the established wave-form of the system is described as possessing a vision white to synchronizing ratio of 7 : 3 in output current, with the synchronizing pulses located at or passing through zero output, it is implied that the black level, about which the ratio is measured, remains fixed under all conditions of modulation.

In the case of the transmitter being described, this level, from the curves of Fig. 26, corresponds to an anode voltage of 5 580 volts and a total anode feed of 1·25 amperes, or an input of 6·9 kW. At vision white the input is very nearly 35 kW, and at peaks of synchronizing pulses it is zero. During modulation, therefore, the h.f. amplifier is keyed from the black level upwards into the high-power area and downwards to zero.

Consideration of the condition will lead to the conclusion that, if the black datum is to be faithfully maintained, the H.T. voltage applied to the anodes of the modulated h.f. amplifier should be kept appreciably constant from zero to full load over a frequency band of preferably 0 to 2·5 Mc./sec., and be free from transients after any type of signal. The requirement extends to zero, or practically zero, frequency owing to the slow variations of general input level, corresponding to mean picture brightness, which occur during transmission. In the case of film these changes to different mean levels frequently occur with abruptness. The requirement is entirely met by using an H.T. anode power source of low and constant impedance over the band of signalling frequencies.

A 3-phase full-wave rectifier of the required power, employing mercury-vapour valves, may be built to an equivalent d.c. resistance of less than 100 Ω if reasonable care is taken in the design of the main transformer and filter chokes. To proportion the circuit so that this value is maintained for a.c. loads and at the same time provide a good level of ripple suppression is costly, and a compromise design is desirable.

Experiment has shown that such a design is practicable, and at the Alexandra Palace and Hayes transmitters a 3-phase full-wave rectifier, fitted with Marconi G.U.3 valves, terminated by a filter circuit in which the ratio $\sqrt{(L/C)}$ is 200, has given satisfactory results.

The electrical capacitance of the H.T. cable from the rectifier to the valve anodes should be prevented from forming a tuned combination with stray or h.f. choke inductance at any frequency within the signalling band, as otherwise the modulation response of the transmitter will be affected. The practice followed at the London Station is to feed each valve through a non-inductive resistance combination of 50 Ω and a quarter-wavelength h.f. choke coil.

This Part of the paper is confined to the theoretical and practical design of the high-power-modulated amplifier of the ultra-short-wave vision transmitter of the London Station, as, in the authors' opinion, wider treatment would obscure the points of major interest. An account of the composition of the complete station, setting out in order the various amplifiers leading up to the final stage, with types of valves and running conditions, is, however, given in Appendix 2.

(8) ACKNOWLEDGMENTS

Finally, the authors desire to express their thanks to Marconi's Wireless Telegraph Co. for permission to publish a description of their work, which is the result of development spread over a considerable period, and to which valuable contributions were made by Mr. F. G. Robb, Mr. W. S. L. Tringham, and Mr. L. Bounds, of the Research and Development Department.

APPENDIX 1

Determination of Compensating Condenser for Grid-Lead Reactance

In the normal process of balancing, the bridge is excited from the grid side, and the balancing condensers are adjusted to give zero current in the anode circuit. To determine the required values of the compensating condensers we must be able to measure the voltage between grid and filament produced by current flowing in the anode circuit. This can be done as follows:—

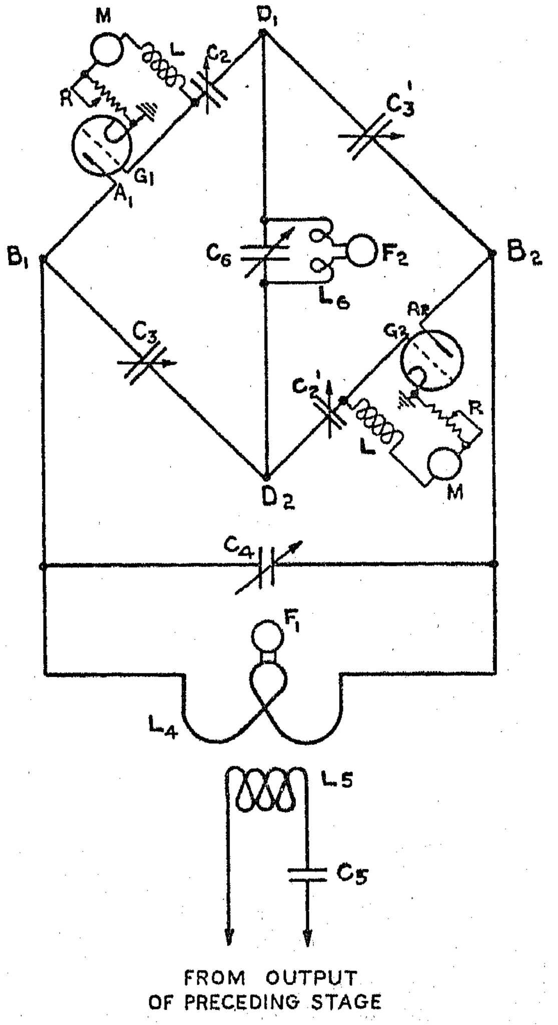

Fig. 29.—Back balance.

Remove the H.T. and grid-bias supplies, but light the valves. Connect a low-reading milliammeter M and resistance R in each grid circuit, as shown in Fig. 29.

The reading of M will be a measure of the voltage between grid and filament, and the sensitivity can be varied by varying the resistance R. (If an accurate measure of the voltage is required, these arrangements can be replaced by a slide-back voltmeter.) Connect the thermoammeter F_1 in shunt to a portion of the anode inductance L_4, and the thermoammeter F_2 (or shunted lamp) in the grid circuit. Supply high-frequency power from the preceding stage via the main output circuit L_5C_5.

Tune the anode circuit, and adjust the coupling of L_5 to L_4 so as to get a suitable reading on F_1. Then tune the grid circuit for a maximum on F_2. Adjust the balancing condensers C_3, C_3' to make the current in F_2 a minimum. Both anode and grid circuit should be kept in tune during the process, and the current in F_1 maintained at a constant value. Take readings of M. Then the capacitances of the compensating condensers C_2, C_2' are altered and the process is repeated, until the value giving a minimum reading on M is found.

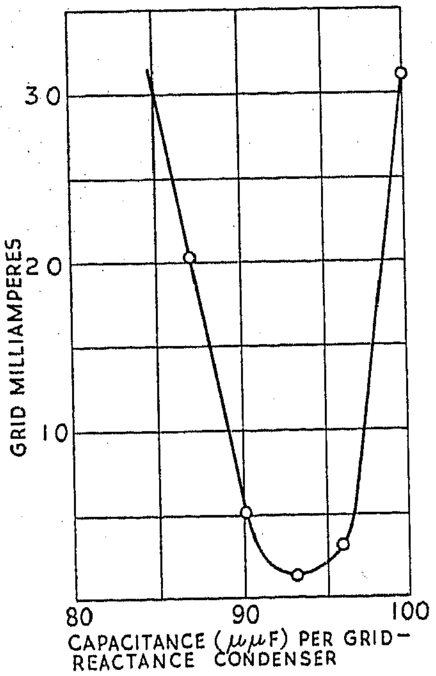

Fig. 30.—C.A.T.9 power amplifier curve of back balance at 46 Mc./sec.

If the bridge points D_1 and D_2 are close together, the process can be shortened. Balance the circuit as previously described. Then join D_1, D_2 by a lead of negligible inductance. Readings of M_1 and M_2 are taken. Then, provided C_2 and C_2' are always kept equal, no further balancing of the bridge should be necessary.

Fig. 30 shows the results obtained with the C.A.T.9 valves at a frequency of 46 Mc./sec., the correct value of C_2 being 94 μμF. The correct value for any other frequency can be deduced from this.

APPENDIX 2

Marconi-E.M.I. Television Radio-Frequency Equipment

The following are the running conditions of the various power amplifiers, with types of valves employed, at the vision transmitter at Alexandra Palace, London, wavelength 6·67 m., frequency 45 Mc./sec.

Power amplifier No.	*Type of valves*	*Running conditions at peak white**	
6th and final	2 C.A.T.9	V_p (volts)	6 000
		I_p, total (amperes)	6·45
		I_p, left valve (amperes)	3·26
		I_p, right valve (amperes)	3·19
		I_g, left valve (mA)	105
		I_g, right valve (mA)	105
		V_g (volts)	—154
		Load amperes	15·7
		kW in	38·7
		kW out	18·6
		Efficiency	48%
5th	2 C.A.T.15	V_p (volts)	5 500
		I_p, total (amperes)	1·59
		$(I_g)^L$ (mA)	164
		$(I_g)^R$ (mA)	222
		V_g (volts)	—400
4th	2 A.C.T.9	V_p (volts)	3 600
		I_p (mA)	620
		I_g (mA)	125
		V_g (volts)	—110
3rd	1 A.C.T.9	V_p (volts)	3 200
		I_p (mA)	280
		I_g (mA)	18
		V_g (volts)	—88
2nd	2 A.C.T.6	V_p (volts)	750
		I_p (mA)	138
		I_g (mA)	12
		V_g (volts)	—6
1st	2 M.P.T.42	V_p (volts)	250
		I_p (mA)	70
		I_g (mA)	—
		V_g (volts)	—20
Doubler	1 M.P.T.42	V_p (volts)	250
		I_p (mA)	45
Master oscillator	1 M.P.T.42	V_p	250
		I_p (mA)	37

* V_p = plate (or anode) voltage; I_p = plate (or anode) current; I_g = grid current; V_g = grid voltage.

[The discussion on this paper will be found on page 100.]

DISCUSSION BEFORE THE INSTITUTION, 21ST APRIL, 1938, ON THE PAPERS BY MESSRS. T. C. MACNAMARA AND D. C. BIRKINSHAW (SEE PAGE 36) AND MESSRS. A. D. BLUMLEIN, C. O. BROWNE, N. E. DAVIS, AND E. GREEN (SEE PAGE 65)

Sir Noel Ashbridge: These papers are of special interest because they record a co-operative effort between a commercial firm and a public utility undertaking guided by a Governmental advisory committee. In addition, valuable work has been done by the wireless-receiver industry in designing and manufacturing complex but nevertheless very reliable apparatus for use by the public. The result has been the setting-up of the first public television service in the world. I should like to pay a tribute to the research staff of the Marconi-E.M.I. Television Co., who have achieved so much in the technical development of this difficult subject.

I should like to point out one or two differences on the economic side between sound broadcasting and vision broadcasting, partly because they may explain why several countries abroad are hesitating before launching a public service such as the one in operation in Great Britain. Let us consider first of all the studio equipment, and compare that at, say, Birmingham with that at Alexandra Palace. The studios at these places each produce about the same number of hours of programme per day, but we find that the cost of the studio equipment for vision is no less than 5 times as great as that required for sound. Again, to carry out an outside broadcast of a boxing match, for example, the apparatus for vision costs about 100 times as much as the apparatus for sound broadcasting. Let us now consider the question of staff; first from the point of view of the numbers required and secondly from the point of view of their ability to carry out the work in the two cases. Comparing the studio staff at Manchester with that at Alexandra Palace, we find that the engineers employed at Manchester number 13, while the equivalent figure for Alexandra Palace is 61, and again the hours of entertainment are roughly the same. Secondly, the training of sufficient engineers quickly enough in the complex technique of television is bound to constitute a difficulty for the next few years.

Another difficulty is that the time for rehearsal is inadequate at present. The producer has to accept, after the few rehearsals he can get in, what the performers will produce themselves, as distinct from what he is trying to get them to produce. It is also necessary to conduct a great many rehearsals without any apparatus at all, because it is not available.

One of the surprising facts about the service is the great reliability of the receivers. At the beginning it was far more difficult to synchronize the picture than to synchronize two alternators in a large power-station, but now a television receiver is no more difficult to adjust than a sound receiver. I have just been away from home for rather more than 2 months, and I gave elaborate instructions as to what was to be done should the television receiver fail during my absence. It has, however, worked satisfactorily 4–5 days a week all the time I have been away, without any skilled adjustment or attention.

The performance of the receivers, good as it is, would be very much better if we could get rid of the two forms of interference which are the most troublesome—from electromedical apparatus and from motor-cars. If only some non-technical means could be found for putting into effect the technical findings of Messrs. Gill and Whitehead* the development of television would be greatly helped.

As regards developments in the future, we have to consider the possibility of establishing television stations in the provinces. This raises the question of linking two transmitters together, because it is inconceivable on economic grounds that each transmitter could be provided with a separate programme produced a mile or two away. There are two obvious types of link: one is the special cable and the other a wireless link, consisting of a number of ultra-short-wave transmitters and receivers. I do not know which would be the cheaper or whether one would introduce more distortion than the other, but I realize that it is desirable to keep out of the ether all the transmissions which it is possible to carry in any other way.

Dealing with the question of coverage, the Television Advisory Committee originally estimated a radius of 25 miles, but I thought this very optimistic and suggested that it should be reduced to 15 miles as far as the public was concerned. It has been found, however, that 25 miles is not the limit, the distances obtained varying in different directions. I think too that the limit with regard to the power of transmitters has not yet been reached; this is one of the most hopeful signs in connection with the extension of the television service to other parts of the country.

Another question to which I should like to refer is that of the 405-line standard, which was adopted after careful consideration by the Committee and will remain in use for a period of at least 3 years. This period will give a good deal of scope for improvement of the picture, both at the transmitting end and at the receiving end. Later it may be necessary to adopt a larger number of lines, in order to give a larger picture with increased definition.

Mr. A. J. Gill: I should like to mention, as an instance of the thoroughness with which the development work in connection with the television service was carried out, that Messrs. Electric and Musical Industries installed in their laboratory nearly 8 miles of the balanced cable referred to on page 57 of the paper by Messrs. Macnamara and Birkinshaw, in order to carry out a complete test over the length which it was proposed to use. It was very interesting to see the result of the comparison between the reception direct from the pick-up and the reception through the 8-mile length of cable: it was almost impossible to distinguish any difference between the two sets of pictures obtained. Another very interesting thing which was shown at the same time was the effect of transmitting the picture signal through the cable but sending the synchronizing signals direct from just across the laboratory. The picture took an appreciable time to go through the cable, and arrived about half a line (approximately 0·00005 sec.) late. A calculation of the speed of transmission gives the value of 160 000 miles per sec., which is about what one would expect.

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* *Journal I.E.E.*, 1938, vol. 83, p. 345; and *Proceedings of the Wireless Section*, 1938, vol. 13, p. 209.

My own interest in this work is largely in connection with the transmission of signals over long distances, for which Messrs. Macnamara and Birkinshaw give three methods—unbalanced coaxial cable, balanced-pair low-capacitance cables, and normal telephone circuits. The first is probably the most economic method of transmission over long distances, but unfortunately the cross-talk sets a limit to the transmission of frequencies below about 100 kilocycles per sec. To avoid this difficulty it would be necessary to move the frequency spectrum up at the transmitting end, by means of terminal equipment something like that used for carrier telephony, and to move the whole spectrum back at the receiving end. To do this would require very complicated apparatus, because of the difficulty of avoiding phase-shift in the equipment; the problem is still being studied, and I think it will be solved in the near future. The balanced cable is, of course, already in use; it is the one which I mentioned seeing demonstrated before it was put in. The work that the B.B.C. is doing on the use of telephone circuits for television purposes is of great interest, because it may offer a solution of the problem of outside broadcasts.

I agree with Mr. Blumlein's remark on page 66 that it is advantageous to transmit pictures with unity γ, and would even suggest the use of a fractional γ. The Post Office on the transatlantic telephone circuit is using a compandor, which produces the equivalent of a fractional γ ($\gamma = 0\cdot5$) in the transmitter, this being automatically corrected at the receiving end. This arrangement gives a lower signal/noise ratio, and I should like to ask Mr. Blumlein whether it would be possible to reduce the γ value of the picture in the transmitting system and increase it again in the receiver.

Mr. G. E. Condliffe: I wish first to comment on the selection of 405 for the number of lines per picture. At the time when the system was decided upon by the Television Advisory Committee, this number of lines represented an advance in definition on any experimental system working on the Continent or in America. The number 405 was a compromise between ideal definition and the practical limitations imposed by the present-day transmitting and receiving equipment. It is unfortunate that the U.S.A. and Germany intend now to standardize on 441 lines, as I question whether any observer, however skilled or critical, would be able to detect the difference between two representative transmissions, one on 405 lines and the other on 441. To provide any appreciable difference, the number of lines would have to be increased to about 600. The difference between the two standards is not immediately important, since exchange of programmes between this country and the Continent is a distant possibility; but it is a definite one. Any unnecessary difference in standards is an obstacle which will tend to delay a natural and desirable development of television broadcasting.

We have our own problems in relaying television programmes to the provinces, and the recent outside broadcasts by cable and radio link are an indication of the possible successful development of the next phase in television broadcasting. The relays so far have been over distances of about 15 miles from Alexandra Palace; the problems involved in covering larger distances are greater but are clearly capable of solution. The quality of these outside broadcasts has recently been improved by removing the radio-link receiver from Alexandra Palace, where the level of interference is high, to a much quieter position at Highgate. Signals received there have been relayed by cable to Alexandra Palace. This appears to be a small-scale model of a possible national scheme in which the Alexandra Palace studios would be linked with the regional television stations by small-power radio transmitters usingly high directive aerials. Sites for the transmitting and receiving aerials could be selected to give maximum range and freedom from interference, use being made of cable to link up relay receivers to the regional transmitters, or to bridge between two relay stations where it would be inconvenient and uneconomical to use a radio link.

Mr. G. C. Marris: The Emitron camera is unrivalled for studio and outside broadcasting, but I doubt whether it is the most suitable type for films.

With regard to film transmission, we have built and had some very satisfactory experience with a 405-line interlaced transmitter using disc methods. The results compare favourably with those obtained at Alexandra Palace; and, when one sees the number of correcting circuits which the Emitron camera requires, one is inclined to ask whether such disc methods may not after all have their place.

In connection with the question of the γ value of the transmission, it is as well to remember that in the early days of broadcasting there was much talk of altering the amplitude ratio, but it was felt that if a straight-line law were abandoned it would be difficult to find a standard to which to work; and I fear that this may be the case also with television transmission. At any rate, if there is to be any departure from the linear law it will require careful watching, because the difficulties affect not only the intention but also the practice. Many of us who regularly look at the pictures transmitted from Alexandra Palace feel that the value of γ wanders a good deal, particularly with certain types of transmission. If we are going to have a correction in the receivers which may also wander from its nominal value, the position may become rather difficult.

We also feel that the present methods of transmission do not give the full quality obtainable from 405-line television, and an attempt to improve the quality by the use of an appreciably greater number of lines would introduce difficulties of receiver design. As the number of lines is increased, the band width required tends to go up very rapidly, and the amplification per valve decreases, leading to greater cost of the receiver. The cost of receivers is already presenting great difficulty, and it is not obvious where drastic reductions can be made.

In the picture signals transmitted from Alexandra Palace the frame-synchronizing impulse comes immediately after the last picture line, and tends to put the whole of the black band for the synchronizing period at the top of the picture. Any variation in that portion of the transmission tends to shift the picture in the frame.

We feel that it would be easier from the point of view of receiver design if that synchronizing period came nearer the middle of the frame blank.

Although it is possible to adjust most receivers so that they interlace perfectly on the Alexandra Palace signals, I suggest that the use of added impulses at the transmitting end to predispose the receiver to interlace properly might be considered. A method of amplitude separation of signals instead of frequency separation might even be employed.

Dealing with the question of controls, the television industry needs to watch very carefully how its demonstrations to the public are carried out, because there is a great tendency, if a demonstration is conducted so that it is visible to a large number of people, to increase the contrast so as to enable people a long way away to see, at the expense of the half-tones. Receivers built for the purpose of such demonstrations are liable to be unsuitable for use in the home, or unnecessarily costly.

Mr. L. H. Bedford: Among the technical triumphs described in the papers three are outstanding, namely the Blumlein wave-form, the compensation of spurious signals by means of tilt-and-bend signals, and the choice of the 405-line standard. The last was a very bold step, in view of the circumstances existing at the time, but it has been well justified; at 405 lines the value of the entertainment receivable increases with increase of lines at a very much slower rate than does the cost. I expect 405 lines to remain our national standard for a considerable time, if not indefinitely.

It seems to me that the greatest problem of television at the moment is not technical but economic. The expenditure on programmes, which includes artistic and technical expenses, is very high, and the difficulty is, in view of the cost of receiving apparatus, to collect a large enough audience to justify them. One powerful approach to an economic solution lies in the internationalization of television programmes. If we are given a group of some thousands of viewers in England and an equal group of viewers (for instance) in France, the efficiency of the complete system is increased by a possible factor of 4 if the programmes can be " cross linked "; for in this way twice the programme material is made available to twice the audience. The implications of this international linking-up are evidently extremely far-reaching, and the problem is not beyond technical solution if, but only if, an international standardization of the wave-form numerics can be established at an early date.

There is one omission in the paper which may have caused considerable surprise; the term " Iconoscope " is conspicuous by its absence. I suggest that an explanation of the relation of the Emitron to the Iconoscope would be of interest.

Mr. P. W. Willans: Messrs. Macnamara and Birkinshaw refer to interference from sources extraneous to the receiver as constituting the limiting condition for reception. The question whether it will ever be technically and commercially possible to effect a substantial reduction in such interference by suppression at the source is one of fundamental importance and has a direct bearing upon the whole problem of television transmission. If, as at present appears probable, we cannot look forward to a drastic reduction in interference, we have to consider very carefully what type of transmission is best adapted to cope with conditions as they are now. Here, in my submission, the primary consideration is interference with the picture; the question of eliminating interference which tends to destroy synchronism raises no fundamentally insuperable difficulties, and admits of possibilities which do not exist in the case of interference with the picture.

Mr. Blumlein mentions in this connection that the question of " positive " versus " negative " modulation is still a matter of controversy. I hope that it is, at any rate, still open. The circumstances in which a decision had to be made on the transmitted wave-form, conditioned as they were by the necessity for designing and manufacturing a commercial transmitter against time, were wholly unfavourable to any satisfactory testing of the points at issue. Indeed, one may doubt whether anything but extended trials under practical working conditions could possibly give the necessary information on which a decision should be based.

I note from Mr. Blumlein's remarks that tests with inverted modulation were carried out and that with negative modulation the picture was broken up by strong interference. It would be interesting to learn more about these tests and, in particular, whether the receivers employed in them were all of one type or whether different synchronizing and scanning arrangements were tested against each other. I should also be glad to know whether the interference, in the case of negative modulation, consisted predominantly of black dots (in contrast with the case of a positively modulated transmission employing a receiver equipped with a simple limiter, to avoid the effect of excess modulation of the cathode-ray tube). Statistically speaking, this would appear probable.

It is to be remarked that any system with " negative modulation " [not merely that specifically referred to in Section (5), page 66] offers the possibility of simple automatic volume control at the receiver. This must be reckoned as an advantage.

My basic argument in favour of allowing the interference to be predominant on the synchronizing side lies in the fact that synchronizing signals are (or should be) strictly repetitive and the intelligence which they are required to transmit can be the result of their cumulative effect. To take a simple example, if a harmonic constituent of the synchronizing signals is selected at the receiver and made to do the work of synchronizing, interference should clearly be very much reduced, and this step may be supplementary to anything that is done by way of limiting the amplitude of the pulses.

I feel that interference difficulties may be worse in the case of scanning oscillators of the type that can be easily triggered off " out of time." I have no liking for the type of scanning system which, so to speak, has to be told at the end of every line when to " fly back." It seems far more logical to go to the other extreme and use scanning oscillators which can be governed easily by truly repetitive synchronizing impulses and not so readily by signals occurring at irregular intervals. But, admittedly, the synchronizing signals must then be truly repetitive. In this connection I am interested to note the developments in the timing system described in connection with Fig. 8 (page 78). The mechanical master-frequency generator, as far as its objects are concerned, represents an advance, but it may well be possible to produce the desired results by electrical means, namely by a system that follows the long-period frequency variations of the mains while ignoring variations of short period.

Mr. R. C. Ballard's patent dealing with interlaced scanning is referred to in Mr. Blumlein's paper. I am bound to say that the inventor appears to be somewhat over-sanguine. According to the patent specification, all that is necessary is to connect up a receiver, apply the line-frequency synchronizing impulses on to one scanning oscillator and the frame-frequency impulses on to another, and perfect interlacing will follow. In practice it appears that special precautions are necessary to produce the required result, but at present these have to be taken at the receiver, as is indicated by British Patent No. 455375 (due to Mr. E. C. Cork and other E.M.I. engineers). In view of the fact that the Marconi–E.M.I. Television Co. control another British Patent, No. 448065, with which troubles with synchronizing of the kind dealt with in Mr. Cork's specification are stated to be avoided, it seems unfortunate that the burden should be placed on the receiver designer.

Mr. Blumlein tells us that in the present transmission we have 5 unused lines at the end of every picture-frame before the transmission of a low-frequency synchronizing signal; we gather from Mr. Condliffe's remarks that an increase in the number of picture lines from 405 to 441 will not give any perceptible improvement in the detail of the picture, so that 5 lines more or less will make no difference, but still Mr. Blumlein considers that these lines should be used as picture lines and proposes to make the necessary alteration for this purpose at an early date.

I should like to plead for consideration of the proposals of Mr. A. V. Bedford (British Patent No. 448065) according to which preparatory signals, of double line frequency, are sent out immediately before the low-frequency signal so that the receiver "does not know the difference" between an odd and an even frame. The advantage, if achieved, would far outweigh the loss of picture lines entailed.

(*Communicated*). In the July, 1938, number of *Electronics* (page 28), particulars have been published of the U.S.A. television standards, and it is interesting to note that negative modulation is recommended (together with positive synchronizing impulses) and also that so-called equalizing pulses are transmitted before and after the vertical synchronizing signal. These equalizing pulses are of double the line frequency and appear to conform to the proposals contained in British Patent No. 448065, to which I referred in the discussion. It is to be presumed, at this stage of development, that these standards have been adopted with due regard to the results obtained in this country and with full knowledge of any dangers that may exist of synchronization being adversely affected.

Mr. F. R. W. Strafford: I wish to make one reference to Mr. Macnamara's remarks about the transmitting aerial used with the mobile equipment. He said they were surprised to find that there was no reciprocity between the two methods of effecting the transmission, by using a high transmitting aerial and a low receiving aerial or vice versa. I should like to point out that the question of reciprocity between aerial systems applies only under the ideal mathematical postulation of free-space conditions, and that the behaviour of an aerial when fed with current is entirely different from its behaviour when receiving a signal, because of the difference in the distribution of current. In the case of the transmitting aerial the current is applied at a point, whereas the receiving aerial is in a uniform field. The different current distribution gives rise in many cases to different directional properties. The effect upon an aerial of the proximity of earthed conducting objects is different when the aerial is transmitting from that produced if the aerial is receiving; because, if the objects are close enough, in the case of reception the aerial is in a pure radiated field, whereas in the case of transmission it is in an inductive field.

(*Communicated*) Since making these remarks I have had an excellent opportunity of conducting certain practical tests which confirm, without any possible doubt, these assumptions.

Dr. L. E. C. Hughes: The symbol gamma refers to the slope of the curve representing the brightness of the reproduced picture in relation to the brightness of the original, and, in photographic terms, measures the contrast. Theoretically the overall gamma value should be unity, so that the reproduced contrast is the same as in the original; if the average brightness of the reproduction is deemed to be correct, then the gradation will be natural. The adjustment of both the average brightness and the contrast should be in the hands of the user, so that by turning knobs he can adjust these variables to suit his particular conditions of ambient illumination, just as various degrees of tone-control should be available in sound-broadcasting reception. The justification for any such adjustment to the taste of the user resides in the fact that the systems are not perfect; if they were, the engineer having complete control over the entire transmitting and receiving system, there would be no case for arbitrary adjustment. The sound-broadcast is not perfect because of various interferences, and the user has a case for asking for a control which enables him to arrive at the best sample of reproduction he can get in the circumstances. In like manner, a contrast-control is as essential in a television receiver as a brightness-control. The television system is not perfect, in that colour is lacking. In cinematography, this lack of colour is compensated by increasing the overall gamma of the projected picture and by moulding the figures and objects on the set with clever lighting. In normal cinemas, the overall gamma appears to be about 1·4 to 1·6, and in amateur work the value may rise to 1·7. The only way to achieve technical stability in television, where the operation of the receivers is not in the hands of the transmitting engineers, as it effectively is when high-grade release prints are being made for cinemas, is to arrange for the transmitting gamma to be equal to unity and to leave the increase to the taste of the recipient. The overall-gamma adjustment should not be the responsibility of the engineer, until the system has been perfected to such an extent that the question cannot arise.

The existing prevalent size of picture would seem to be inadequate. The optimum width of angle of vision appears to be, from experience in cinemas, that obtained at a distance equal to four widths of the screen. It is evident from experiments with opera glasses that widening the picture only a moderate amount greatly increases the interest, indicating that the potentiality of definition is in the system, but is not used because of the smallness of the picture in normal viewing conditions. When one experiences a picture of the normal programme some 5 ft. wide, the interest becomes so great that varying defects of the cameras are forced on one. Incidentally, it appears that no amount of public demonstration is likely to increase the permanent public interest in television, mainly because of the psychological atmosphere. Personal experience in the home without distractions is likely to be more effective in building a television audience. This is realized by firms who are willing to hire a receiver for a week or so at a nominal charge.

On the programme side, it is surprising that the B.B.C. has not used film for its own items. There is considerable value in "shooting" the required images on film for subsequent telecine scanning, as it permits artists to make the images at greater convenience. These images can be made at any studio available without congesting the floor for the impromptu work, and this technique permits a degree of editing which is realized to the full in cinematograph work. Can it be claimed that the public prefer artistic performances which are liable to go wrong, because of long sequences, to the more perfected version which could be obtained by film methods? With the present standard of transmission, film economy is available in the use of sub-standard stock.

Mr. K. S. Davies (*communicated*): In the sound broadcasting service, transmitter development has been able to proceed continuously from its inception without affecting in any way receivers already in use. But in television the transmitter and receiver are much more closely inter-related and, in deciding upon television standards, the fact must be borne prominently in mind that once the service has been established, and a considerable number of receivers are in use, it will be very difficult to make any radical alteration in the system of transmission. The selection of the wave-form to be transmitted in a national television service thus places a very great responsibility upon those who are entrusted with the choice.

After nearly 2 years' experience of the working of the London Television Station we have every reason to believe that the choice has been wisely made. While very good pictures are being transmitted at the present time, one has only to examine an electrically transmitted photograph of an equal number of lines to see that considerable room has been left for improvement within the present standards.

The use of interlaced scanning has yielded a very good solution to the problem of eliminating flicker without increasing the transmitted band-width, and the "odd-line" method actually employed has an added advantage in that the amount of apparatus in the time-base circuits is not increased. The successful use of odd-line interlacing does, however, call for very precise synchronizing of the frame time-base. It has been suggested that the lack of symmetry between the signals at the ends of the odd and the even frames in the present transmissions is responsible for the faulty interlacing of many commercial receivers. This asymmetry, however, can only affect such receivers as rely on integration as the means of frame-impulse selection, but both theoretical and practical considerations show that satisfactory performance can hardly be expected from this type of circuit. For the impulse obtained from an integrating circuit must necessarily be of very rounded wave-front and thus cannot ensure the exact timing of the frame time-base which is essential.

For this reason, I believe, one of the experimental systems at present being very successfully used in America employs amplitude separation between the line and frame impulses. The chief advantage claimed for this system is that the frame impulse can be given the same steepness of wave-front as the line impulse, so that the required accuracy in timing is readily obtained.

But it is possible in the case of the present transmissions from the London Station to obtain a precisely similar result, and by the use of no more apparatus in the receiver than would be required for amplitude discrimination. This method depends upon the use of the trailing edge of the first of the eight frame impulses, which can quite easily be selected, and which affords a frame-synchronizing impulse equal in steepness to a line impulse.* Mr. Blumlein points out the advantages of working in such way that all synchronizing impulses reduce the carrier to zero. With amplitude separation either the line or the frame impulse must be represented by a finite value of received carrier, and therefore one or other of the time-bases will be rendered more liable to disturbance by strong interference. It appears, therefore, that amplitude separation can offer no advantage over the method at present in use and, further, that no modification of the existing wave-form can be expected to effect either an appreciable reduction in cost or an improvement in performance of commercial receiving sets.

Mr. H. G. M. Spratt (*communicated*): It would be interesting to know whether the smoothing and impedance-matching in the mobile van equipment is of the same standard as that at Alexandra Palace, and, if so, how it was possible to dispense with a 500-cycle supply.

Mr. Blumlein stated that the absence of identical preparatory signals before each frame-synchronizing train of pulses was a disadvantage only in a comparatively few limiting circuits where the time-constant during the synchronizing pulses was shorter than that during the remainder of the line. This statement appears to justify the insertion of one line at least having two line-pulses at half-line intervals before the train of frame pulses. The extra complication thus involved in the pulse generators should be negligible. Furthermore, it cannot be argued that no room exists for these pulses, seeing that at present 5 blank lines are transmitted before the frame-synchronizing train and in any case the maximum interval between frames is fixed at 10 lines. In view of the greater flexibility in limiter design which this modification would provide, I should be glad to know why it has not been carried out and is apparently not contemplated.

Mr. J. C. Wilson (U.S.A.) (*communicated*): I shall confine my comments to the paper by Messrs. Blumlein, Browne, Davis, and Green.

The discussion of reasons for the choice of a gamma value of unity in the transmitter [Part I, Section (3)] is incomplete; if it is desirable to apply correction at the receiver to raise the gamma value to about 1·6, on account of the relative diminution of the effect of small parasitic receiver noises thereby obtained, then *a fortiori* it is advantageous to make use of a transmitter modulation characteristic corresponding to a gamma value less than unity, the better to override channel noise. The utility of this for radio transmission is well known and has been demonstrated in practice.* As a matter of fact, by a fortunate accident the iconoscope (or Emitron) is adapted to give the same advantage in overriding ultimate valve and thermal noise at the start of the vision channel, in that it exhibits a markedly curvilinear brightness/signal characteristic, the curvature being in correct sense.†

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* H. A. Fairhurst: British Patent No. 484412.

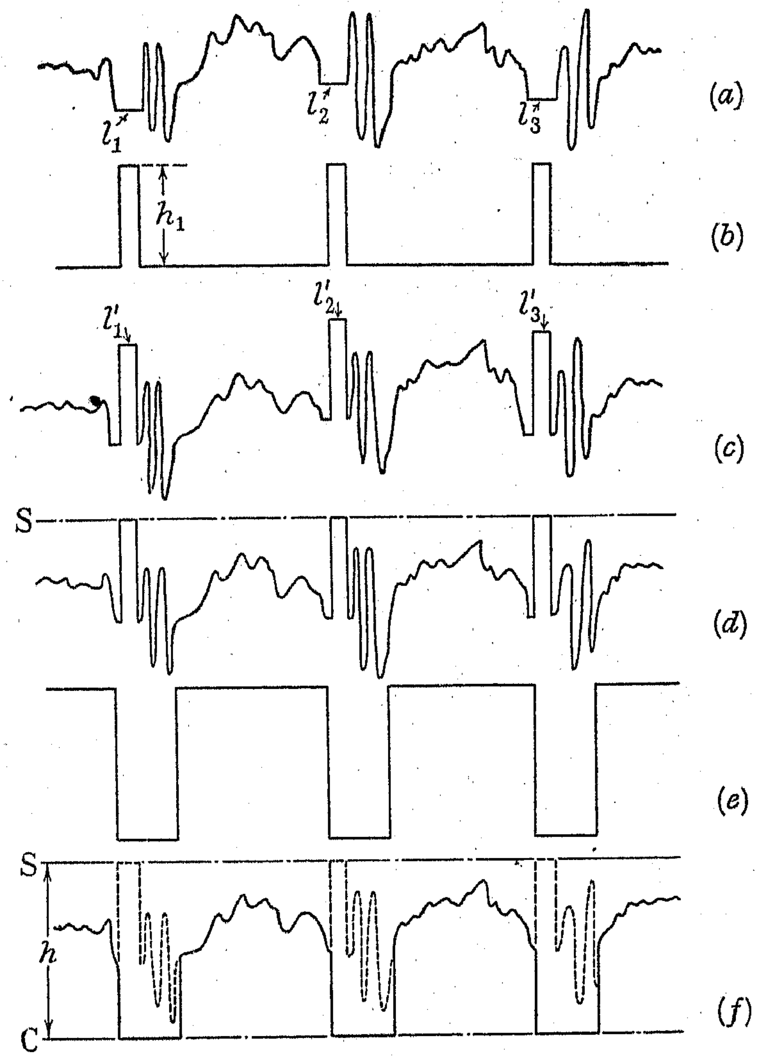

Fig. A

To call the use of the "blackest" signal derived from the picture for level-locking "in some respects a compromise" [Part II, Section (4)] is euphemistic, to say the least. It is surprising that the authors adopt this view, and method, having regard to the fact that convenient and much more acceptable ways of keeping the black level at true or "picture black" are available. For instance, with reference to Fig. A, consider the video signal, complete with surge components, proceeding from the camera, as shown at (*a*), in which datum levels l_1, l_2, l_3, etc., have been inserted bearing a fixed relation to "picture-black" (for example, by running the scanning beam on to a plain metal strip of uniform secondary-emissive properties independent of the image brightness falling on it, at the termination of each scanning line); after passing of the signal through a portion of an amplifying system the levels l_1, l_2, and l_3 will, of course, generally lie at different voltage heights, as shown, owing to loss of d.c. and low-frequency components. To this signal is added, in timed relationship, the constant-amplitude pulses (*b*), resulting in the combined wave-form shown at (*c*), in which the levels l_1, l_2, l_3, etc., are represented by new levels l_1', l_2', l_3', etc., lying outside the range of voltage ordinates occupied by the video and surge components.

The signal can now be stabilized* on the tips of the injected pulses which align themselves on the S-level as shown at (*d*). A blanking wave-form of the type shown at (*e*), of sufficient amplitude to swamp the surge and injected pulse components completely, is then combined with the stabilized wave in such a manner as to run a valve of the system to cut-off at the level C, as shown at (*f*); the rectangular portions of this wave are then prepared for receipt of the synchronizing pulses or other information as desired. Moreover, if the instantaneous signal value represented by the original levels l_1, l_2, l_3, etc., with respect to true or "picture-black" is h_2 and the equivalent voltage-height of the (*b*)-pulses is h_1, then the level C will represent the proper tone of black if $h = h_1 + h_2$, where h is the equivalent voltage-separation between the S-level and the C-level.

That reference to some such proper method of level-locking should have been omitted in the paper and replaced by an improper one is all the more surprising because the method just described is somewhat similar to that given in Reference (2), page 86.†

It may be objected to the method described that it involves the insertion of a signal-segment of standard level during the strip underlap interval, where time is already severely limited by the difficulty of obtaining a fast enough retrace stroke in the scanning circuits, having regard to the length of cables required for studio operation, etc. Also it requires that registration of the scanned area with a particular portion of the matrix in the camera shall be very exact. The former difficulty is one of degree and expense, and in relatively complex and expensive transmission installations the necessary measures can be taken. The latter difficulty is avoided by making the level-inserting element (copper strip or the like) in the tube play a part also in the scanning operation, so that the scanned area automatically aligns itself, like a company of soldiers dressing by the right against a brick wall.

With regard to the choice of positive polarity of transmission [Part I, Section (14)], there are many confusing arguments to be brought up for and against, a majority of them depending upon questions of degree. It has been pointed out, however, by Mr. H. M. Lewis, whose view I adopt, that an absolute advantage in favour of negative polarity lies in the fact that with positive modulation as ordinarily practised there exist only two available reference levels in the received signal (namely zero-carrier and the blanking or "black" level), whereas with negative there are three (zero-carrier, blanking, and peak-power levels). The extra intelligence inherent in a negatively modulated signal, including the d.c. component, in the long run overweighs the transitory advantages of positive transmission. Amongst other uses it has the obvious one of providing a peak reference level for obtaining automatic volume control in a simple manner at the receiver.

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* R. C. Mathes and S. B. Wright: *Bell System Technical Journal*, 1934, vol. 13, p. 315.

† V. K. Zworykin, G. A. Morton, and L. E. Flory: *Proceedings of the Institute of Radio Engineers*, 1937, vol. 25, p. 1071.

* J. C. Wilson: "Television Engineering" (Pitman), p. 348.

† British Patent Specification No. 450675.

A small correction is required in connection with Fig. 1 in which no time-interval is shown before the commencement of frame-synchronizing pulses, whereas in Part I, Section (13), it is stated that five additional " black " lines are put in before the synchronizing pulses.

THE AUTHORS' REPLIES TO THE DISCUSSION BEFORE THE INSTITUTION

Messrs. T. C. Macnamara and **D. C. Birkinshaw** (*in reply*): Sir Noel Ashbridge mentioned one or two economic differences between sound broadcasting and television, and in this connection it is interesting to compare the present situation as regards rehearsals. In the case of a production over the sound broadcasting system some 5 hours of rehearsal are necessary per hour of transmission. It will be at once evident that in the case of television at least this, and preferably a greater, ratio of rehearsal to transmission time is required, since the rehearsal involves, in addition, the setting of lights, considerations of make-up and costume, and, moreover, artists cannot read their parts from scripts. At present, rehearsal/transmission time ratios of only 1 or 2 to 1 are being realized, and although a great deal can be done by means of preliminary rehearsals conducted without apparatus, it is essential, if the standard of presentation is to be improved, for facilities to be provided enabling more rehearsal time to be spent in the studio. It is primarily for this reason that a second studio has recently been put into service, and a third is at present in the course of being prepared at the Alexandra Palace.

Mr. Gill referred to the work that the B.B.C. is doing on the use of telephone circuits for television purposes. In this connection it is interesting to note that it has already been found possible to send vision signals over a length of 4 miles of ordinary telephone circuit. The technical arrangements necessitated the use of special terminal equipment, and of two intermediate repeaters with equalizers installed at the two Post Office exchanges en route. It was, however, unnecessary to interfere with the lines themselves. We should like to record the fact that the London Telephone Service has been most helpful in providing the necessary facilities for experiment in this direction. The transmission of television signals over normal telephone circuits is considered to be a useful method of extending the number of possible television outside broadcasts which can be carried out with the aid of the balanced cable circuit, and, if successful results are consistently achieved, there will, no doubt, be ample justification for an extension of the balanced cable.

It is also considered that the potentialities of the radio link between outside broadcast points and the London Television Station are capable of further development, which should lead to an extension of the maximum distance from the Alexandra Palace at which it is now possible to handle such broadcasts, and which is now some 15 miles.

Mr. Marris raises an important point when he refers to the question of demonstrating television receivers to the public. The television receiver designed for home use cannot be successfully seen by a large number of people at once, and, where this is attempted, the overloading of the tube, due to the use of an excessive contrast adjustment, will inevitably give those nearest to the receiver an unfavourable impression of the picture. We consider that, with the receivers available at present, the maximum number of people who can simultaneously and satisfactorily see a picture is not much greater than 12.

Mr. Bedford very rightly refers to the difficulty created by the high cost of television programmes, and suggests as a remedy the " internationalization " of programmes. This is certainly an attractive possibility, but it is, of course, subject to many difficulties both technical and non-technical, the latter including the question of differences of languages. If the technical difficulties can be overcome, however, it might be found possible to devise a proportion of television programme material which would carry its entertainment value in the picture rather than in the sound, and would therefore be acceptable to an international audience.

Mr. Willans made reference to the question of interference from sources extraneous to the receiver, and is not optimistic as to the possibility of any improvement in this respect. In view of the fact that such interference largely emanates at present from motor-car ignition systems, it does seem to us that some amelioration of this difficulty could be obtained by negotiation and, possibly, by legislation. As regards the relative effect of the interference on the picture and on the synchronizing, the system was designed so that interference would manifest itself primarily on the picture, and that no serious effect on the synchronizing would be observed until the picture had been rendered unacceptable by interference. As a result of many observations it is considered that the design of the system is satisfactory in this respect.

Concerning Mr. Strafford's remarks upon the subject of reciprocity between aerial systems, we agree that further experimental work is needed to determine the conditions in which reciprocity applies to systems employing ultra-short waves. The point is rather that the absolute level of interference received with a high receiving aerial may be greater than with a low aerial. This is an entirely separate matter which may complicate the issue but has no bearing upon the principle of reciprocity, although the conclusion is that more favourable results are likely to be received with a high transmitting aerial and a low receiving aerial than vice versa.

Dr. Hughes made some observations upon the most desirable size of a received picture. It will be generally agreed that an increase of picture size is desirable but it should be remembered that this will bring certain problems to those responsible for the transmissions. It is already known that the studio technique which should be adopted in production is considerably influenced by the size of the reproduced picture. With the size at present available it is found desirable to employ what may be described as an intimate production technique, but observations which have been made with comparatively large received pictures show that such a technique is not suitable for such pictures, and there is no doubt that when the public are generally equipped with large picture receivers the studio technique will be quite different from that employed to-day. An interesting problem therefore arises in the intermediate period when some viewers have provided themselves with modern large-picture receivers, while others still retain the types in use to-day.

Dr. Hughes also mentions the question of the B.B.C. "shooting" its own film. It is improbable that it will be found desirable to introduce film as an intermediate stage in the production of the general run of television programmes, but there is a considerable field in the employment of specially-taken films to supplement normal productions and introduce into them scenes which could not be conveniently set up in the studio. In this connection, it should be mentioned that the B.B.C. has for some time been "shooting" a considerable amount of film for this purpose.

Messrs. A. D. Blumlein, C. O. Browne, N. E. Davis, and **E. Green** (*in reply*): A number of speakers have raised the question of the best γ value to use, and the advisability of introducing preparatory signals before the frame-synchronizing signals. These points will be dealt with first, before the remarks of individual speakers are replied to.

Messrs. Gill, Hughes, and Wilson, have suggested that a lower γ value than unity might be used at the transmitter, and subsequently corrected at the receiver. It might be argued that the human eye has an almost logarithmic sensitivity and so desirably the transmitter modulation should be a logarithm of the original brightness, the receiver having an exponential characteristic so that background "noise" would be equally noticeable at all levels. However, for a picture viewed as a whole, the eye does not appear to have logarithmic sensitivity as regards noticing low-level interference. If a television picture is examined with low-level interference introduced in such a manner as to be modified by a γ of about 2 when converted to light intensities, it will be noticed that the interference is hardly more noticeable in the blacks than in the whites, provided, of course, that the focus is maintained for the high lights. This latter requirement is important since in practice the surface noise in the high lights is usually obliterated by the less perfect focus of the cathode-ray tube. This leads to the conclusion that a slight theoretical improvement might be obtained by working with a transmitted γ slightly less than unity. The practical return would be almost negligible since near the optimum the curve of advantage is flat-topped. Further, it must be remembered that a very high γ at the receiver makes intense interference (such as motor-car interference) appear very objectionable.

Messrs. Marris, Willans, Spratt, and Wilson, have asked for preparatory signals before the frame-synchronizing signal. Mr. Davies does not want them, nor presumably does Mr. Bedford. It must be pointed out again that we know of only one type of circuit which is the better for preparatory signals, whereas there are a number of circuit types where such signals are quite unnecessary. Mr. Willans has referred to one, and Mr. Davies has pointed out the extremely elegant type due to Mr. Fairhurst. Using the integrating-type circuit without preparatory pulses, the interlace is slightly misplaced, but our practical experience is that any real trouble in interlacing is usually due to coupling between the scanning generators, which would be completely unaffected by the preparatory signals. Mr. Spratt has suggested two lines of preparatory signals, whereas apparently Mr. Willans requires perfection. To give a good result with a true integrating circuit (very long time-constant) a very large number of preparatory lines are required, perfection being achieved when the whole frame period is used in preparation for the frame-synchronizing pulse and no time is wasted in picture transmission. In practice a fair number of lines must be utilized for preparatory pulses if they are to be worth sending at all. This time is therefore wasted, as it is not used either to accommodate the receiver flyback or to give the receiver time to recover from any slight upset of line scanning due to the latter having been triggered by frame-synchronizing pulses. Mr. Willans is astonished that an attempt should be made to improve the efficiency by 5 % by reducing the frame interval from 20 to 10 lines, whereas Mr. Condliffe is sure that a change from 405 to 441 lines would produce no noticeable improvement of picture. Of course, such a change accompanied by a 20 % increase of band width would give a better picture. However, for a given band width (be it that appropriate to 405 or to 441) a 10 % change in number of lines would slightly interchange horizontal and vertical definition, and would produce negligible change in picture quality. The increase of 10 picture lines in each frame means a 5 % improvement without increase of band width.

Mr. Willans finally points out that the new U.S.A. television standards include preparatory pulses not only before but gratuitously after the frame-synchronizing pulses, and that this standard is presumably the result of much consideration. It is to be noted that the new German standard,* presumably decided upon after similar consideration, does not employ any preparatory pulses. Mr. Ballard's patent may appear sanguine but it has the right idea, and it must be repeated that the practical difficulties are usually due to stray couplings which prevent the scanning generators running uniformly as required by the Ballard arrangement.

It was appreciated that it would be possible to construct a mechanical film transmitter, but the correcting circuits to which Mr. Marris refers for the Emitron film transmitter are already part of the system and are used, of course, for all cameras. The Emitron film transmitters are synchronized from a centralized source of timing signals so that they may be mixed with the studio cameras if required, whereas it is well-nigh impossible to synchronize a mechanical transmitter with sufficient accuracy to provide the same facility. A solution to this difficulty is to use the mechanical transmitter as the source of timing signals, but, even so, the immediate disadvantages are obvious, and this method does not lend itself kindly to an extension of the television station with further studios each with the necessary camera control equipment.

Mr. Marris has suggested a consideration of amplitude selection for frame- and line-synchronizing signals. This system demands that not only must the vision signals lie totally on the straight part of any amplifier, modulation, or detection characteristics, but similarly the synchronizing signals must lie on linear portions of the characteristic. With positive modulation using zero carrier for the larger synchronizing pulse, the modulation and detection are extremely difficult if the larger synchronizing pulse is not to be crushed. With negative modulation all the advantage of a simple line-to-line A.V.C. is abandoned.

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* D. VON OETTINGEN, R. URTEL, and G. WEISS: *T.F.T.*, 1938, vol. 27, p. 158.

In answer to Mr. Bedford's question regarding the relation of the Emitron to its American counterpart, the Iconoscope, it should be stated that these are trade names and apply to two entirely independent developments of the cathode-ray tube for transmitting images proposed by Campbell Swinton in 1908.[*] [†] Because the same fundamental principles are involved in the two tubes, it is not surprising that they should be generally similar in physical appearance, but the differences of the two tubes which are now known to exist are accounted for by the dissimilar methods adopted in their manufacture.

With regard to the "Super-Emitron," this is a further development of the Campbell Swinton idea, but it involves an entirely new principle and was first developed in the E.M.I. laboratories.[‡] This new principle has been adopted in the American version of the tube, which has been called the "Super-Iconoscope."

Mr. Willans feels that negative modulation may still be the correct solution. As regards the tests referred to in the first part of the paper, the receivers used for testing negative modulation had no special limiter to limit interference in the receiver output to a value corresponding to the peak synchronizing amplitude. The time-base, however, was designed to be quasi-periodic, in that the scanning generators were only capable of being triggered by an incoming pulse shortly before the end of the scanned line. Even with a critical adjustment, interference tended to cause a "ragged" picture, even if incapable of seriously displacing the lines. It is agreed, of course, that suitable limiters can make negative and positive modulation practically equivalent, but such limiters are a necessity with negative modulation, and it is the cheap receiver (without A.V.C.) which must be kept cheap.

The impedance-matching of the circuits used in the modulation amplifiers for the mobile transmitter, to which Mr. Spratt refers, is carried out with the same care as for the modulation amplifiers described in this paper. The mobile transmitter, however, is of considerably lower power, and so requires less swing from the modulation amplifiers. It was therefore more economical to provide larger smoothing components and to increase the power-handling capacity of the amplifiers to produce the swing required, than to install a 500-cycle supply.

Mr. Wilson elaborates a method of d.c. establishment which is agreed to be essentially the same as that described in Reference (2) of the paper, but these and similar methods suffer from the disadvantage that the reference signal is generated at the edge of the picture where the tilting conditions are sometimes difficult. The method of establishment of the direct component from a black border as described in Reference (2) has been used experimentally for film transmission, and by using the circuits given in Reference (12) the result was obtained without the complication of the method Mr. Wilson proposes.

Mr. Wilson's argument for negative modulation appears to be that it provides a means by which the amplitude of the synchronizing signals can be checked in terms of the difference between black level and zero carrier, which incidentally cannot be peak white unless perfectly linear modulators and detectors are invented. There may be a use for three reference levels, but the use is not obvious.

As regards Mr. Wilson's final remark, it is pointed out in Section (*e*) of the Appendix to Part I that the 10 lines are a minimum interval, and in Section (*m*) that initially this minimum may be exceeded. Also, in Section (13) of Part I it is explained that ultimately it is hoped that the 10-line interval will be realized.

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[*] *Nature*, 1908, vol. 78, p. 151.

[†] *Journal of the Röntgen Society*, 1912, vol. 8, p. 1.

[‡] H. G. LUBSZYNSKI and S. RODDA: British Patent No. 442666.

DISCUSSION ON
"THE DISTRIBUTION OF ULTRA-HIGH-FREQUENCY CURRENTS IN LONG TRANSMITTING AND RECEIVING ANTENNAE"*

Dr. Denis Taylor (*communicated*): Some years ago, whilst carrying out an investigation on the current distribution in loop aerials, I became interested in the ideas put forward by Korshenewsky of the current distribution in open-wire aerials. As Korshenewsky's ideas explained some of my own results with a loop aerial, I carried out a number of confirmatory experiments, but interest in other things prevented me from making a complete investigation. I am therefore glad to see that the authors have pursued the subject further and obtained such good agreement between theory and experiment. My own results, such as they are, confirm their work, but as my experimental technique was somewhat different a short account of it may be of interest.

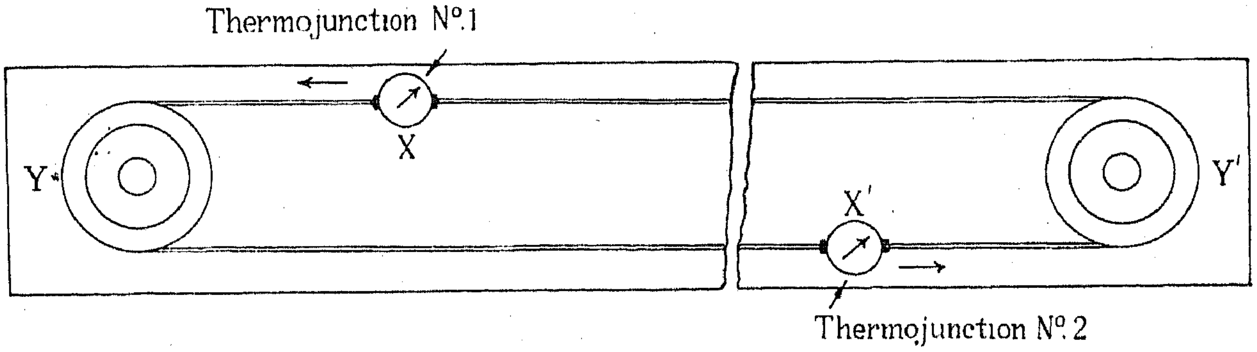

Fig. A

Experiments were carried out at wavelengths from 3 to 5 m. Two D.A.60 Osram valves were used in push-pull in a modified Hartley circuit,† and to this was coupled a dipole aerial of adjustable length. With this apparatus, sufficient power was obtained for adequate radiation over a distance of about 10 wavelengths. The dipole aerial was used horizontally so as to obtain a horizontally polarized wave.

The receiving aerial was of the type shown in Fig. A. Y and Y′ are two small pulleys, and round these is stretched a loop of flexible copper wire. Inserted in this loop are two vacuum thermojunctions X and X′, the points of connection being so chosen that the junctions are always symmetrically placed with respect to Y and Y′. This aerial system was erected parallel to the transmitting dipole, readings of X and X′ were observed as the pulleys were gradually rotated, and a continuous observation of the current and its variation along the length of the antenna was thus made possible. Some care had to be taken in choosing two thermojunctions with exactly the same characteristics, but provided this was done X and X′ showed almost exactly the same variation of current.

So as to avoid long trailing leads the measuring instruments were carried in small baskets, which moved directly underneath the thermojunctions X and X′. Observations were made using a telescope and a periscopic mirror arrangement, and thus errors due to the presence of a moving observer were avoided.

Fig. B shows the current distribution obtained in an experiment carried out with a wavelength of 3·6 m., the length of the aerial being 5·2 m.

I believe this method possesses certain advantages over that used by the authors, in that (i) the whole experiment can be carried out without the receiving aerial being interfered with; (ii) a continuous observation of the current is possible; and (iii) the system is always symmetrical about the midpoint of the antenna. I shall be interested to learn the authors' views on this subject, as perhaps the method possesses disadvantages which their more complete investigation has brought to light.

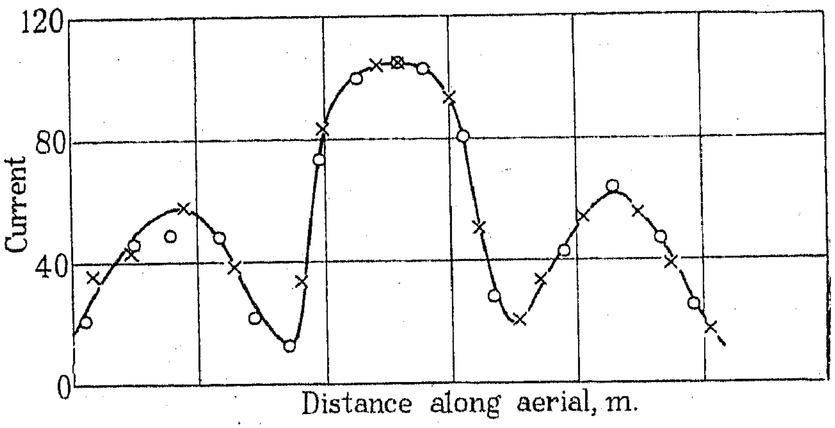

Fig. B

l = 5·2 m. ⊙ Experimental points with instrument X.
λ = 3·6 m. × Experimental points with instrument X′.

The method of moving the thermojunction from point to point in the antenna by unscrewing a portion from one end and screwing it on to the other seems to be quite satisfactory, but I should like to ask whether the authors consider their second method of bridging the antenna with a movable thermojunction to be equally satisfactory. This method was, I believe, first used by Walmsley* in measuring the current distribution in transmission lines, but in applying the method to a receiving aerial where the current is necessarily low I have always found difficulty with the contacts and the variation of contact resistance.

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* Paper by Prof. L. S. Palmer and Mr. K. G. Gillard (see vol. 13, p. 285). Reprinted from *Journal I.E.E.*, 1939, vol. 84, p. 293.

† *Proceedings of the Physical Society*, 1934, vol. 46, p. 76; and 1936, vol. 48, p. 111.

Finally, I should like to inquire whether the authors have found it necessary to use a special type of vacuum thermojunction in their receiving aerial or to modify the experimental procedure with wavelengths of the order of 60 cm. Reduction of the wavelength certainly reduces the size of the aerial systems, and enables the current distribution in aerials comparable in length with the wavelength to be studied without the apparatus becoming cumbersome, but it would seem that some difficulties must necessarily be introduced in the experimental technique.

Prof. L. S. Palmer and **Mr. K. G. Gillard** (*in reply*): It is pleasing to see Dr. Taylor's current-distribution curve for a ratio of $l/\lambda = 1\cdot44$. The general form of the curve is obviously similar to that shown in Fig. 9(*d*) of our paper, which is for l/λ (corrected) $= 1\cdot53$. Dr. Taylor's graph cannot be compared readily with any theoretical curve because the value of the "equivalent length" (in cm. of aerial wire) of his thermojunction for the particular frequency he used, and the effects of phase-changes near the pulleys, have not, presumably, been determined. These effects may probably be equivalent to a length of aerial wire of the order of perhaps 8 or 10 cm. at the frequency he employed. The corrected value of l/λ for his experiments would then be somewhere in the neighbourhood of $1\cdot47$. The agreement between our results is then even more satisfactory.

The economy in time and the general ease of manipulation associated with Dr. Taylor's apparatus is apparent, and it would appear that the mutual reactions between the two wires do not appreciably affect the current distribution, although there must, we think, be some current-component flowing round the closed loop circuit the effects of which will vary with the dimensions of the loop.

A modification of Dr. Taylor's method is to use spring pulleys which wind up the wire at one end while at the same time more wire is unwound from the other end. This method has, however, the disadvantage that the phase-changes on reflection at the ends of the aerial are not quite constant. The method of bridging a short length of the aerial with a sliding thermojunction is not so satisfactory at ultra-high frequencies, and we have now discarded it.

Very small vacuum thermojunctions, if completely stripped of case and external plug terminals and directly soldered into the aerial wire, seem to be quite suitable for ultra-high-frequency work, but need calibrating for each wavelength because their "equivalent length" varies appreciably.

The difficulties of technique increase very rapidly with frequency and, when absolute current measurements are required, the accuracy of the results may be seriously reduced. Even with low power, it is not safe to carry out experiments within the four walls of an ordinary room, owing to the spurious results which usually arise due to reflections.

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* *Journal I.E.E.*, 1931, vol. 69, p. 311; and *Proceedings of the Wireless Section*, 1931, vol. 6, p. 15.

MEETINGS OF THE WIRELESS SECTION

146TH MEETING OF THE WIRELESS SECTION, 2nd NOVEMBER, 1938

Mr. T. Wadsworth, M.Sc., the retiring Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 4th May, 1938, were taken as read and were confirmed and signed.

Mr. Wadsworth announced the Council's award of Premiums (see *Journal I.E.E.*, vol. 82, page 698) for papers read before the Section during the session 1937–38. He then vacated the chair, which was taken by the new Chairman, **Mr. A. J. Gill, B.Sc.(Eng.)**

A vote of thanks to Mr. Wadsworth for his services as Chairman during the session 1937–38, proposed by Mr. H. Bishop, B.Sc.(Eng.), and seconded by Mr. R. P. G. Denman, M.A., was carried with acclamation.

Mr. Gill then delivered his Inaugural Address (see page 1).

A vote of thanks to the Chairman for his Address, proposed by Mr. Wadsworth, was carried with acclamation.

14TH INFORMAL MEETING OF THE WIRELESS SECTION, 22ND NOVEMBER, 1938

Mr. A. J. Gill, B.Sc.(Eng.), Chairman of the Section, took the chair at 6.30 p.m.

The minutes of the Informal Meeting held on the 15th March, 1938, were taken as read and were confirmed and signed.

A discussion, opened by Mr. T. E. Goldup, took place on "Receiving Valves."

At the conclusion of the discussion a vote of thanks was accorded to Mr. Goldup for his introductory remarks.